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The Effect of a Monocular Helmet-Mounted Display on Aircrew Health: A Cohort Study of Apache AH Mk 1 Pilots Four-Year Review

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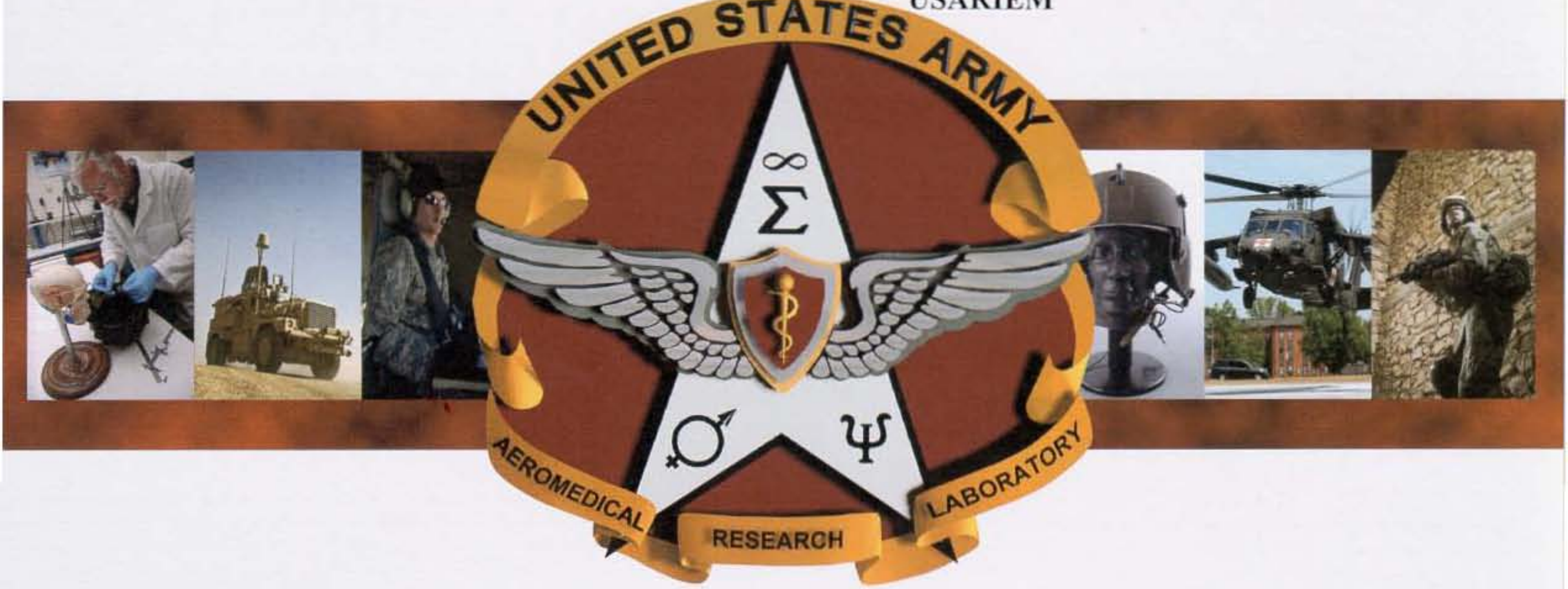

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14. ABSTRACT
This is the second biennial interim report for the study titled The Effect of a Monocular Helmet-Mounted Display on Aircrew Health: A Cohort Study of Apache AH Mk 1 Pilots. The principal aim of this occupational health study is to determine if the use of the monocular Integrated Helmet and Display Sighting System (IHADSS) helmet-mounted display (HMD) in the British Army's Apache AH Mk 1 attack helicopter has any long-term effect on visual performance. Additional information concerning other unique problems of the Apache AH Mk 1 aircrew is elicited as a secondary objective. This study is a collaborative effort between the British Army and the U.S. Army and is conducted under the auspices of The Technical Cooperative Program (TTCP), Subgroup U, Technical Panel 7 (Human Factors in the Aviation Environment). The current report presents the longitudinal data analysis for the approximate 5-year period January 2000 to December 2004. Visual performance data are examined for within- and between-subject differences for seven exposed (AH Mk 1) and 23 control subjects with a minimum of 3 years of measured data.

15. SUBJECT TERMS
Occupational health, Monocular, Integrated Helmet and Display Sighting System, IHADSS, Helmet-mounted display, HMD, Apache helicopter, Visual performance

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Executive summary

Purpose and scope of document

This is the second biennial interim report for the study titled *The Effect of a Monocular Helmet-Mounted Display on Aircrew Health: A Cohort Study of Apache AH Mk 1 Pilots*. The principal aim of this occupational health study is to determine if the use of the monocular Integrated Helmet and Display Sighting System (IHADSS) helmet-mounted display (HMD) in the British Army's Apache AH Mk 1 attack helicopter has any long-term effect on visual performance. Additional information concerning other unique problems of the Apache AH Mk 1 aircrew is elicited as a secondary objective. This study is a collaborative effort between the British Army and the U.S. Army and is conducted under the auspices of The Technical Cooperative Program (TTCP), Subgroup U, Technical Panel 7 (Human Factors in the Aviation Environment).

The first interim report covered the period January 2000 to May 2002 and was documented in USAARL Report No. 2004-18, "The Effect of a Monocular Helmet-Mounted Display on Aircrew Health: A Cohort Study of Apache AH Mk 1 Pilots, Two-Year Baseline Review." The first report documented baseline data for 117 subject pilots (AH Mk 1 exposed, n = 14; control, n = 103) enrolled from the period 17 November 2000 to 23 May 2002.

The current report presents the longitudinal data analysis for the approximate 5-year period January 2000 to December 2004.[1] Visual performance data are examined for within- and between-subject differences for seven exposed (AH Mk 1) and 23 control subjects with a minimum of 3 years of measured data. This report fulfils the requirement set forth in the study protocol to provide biennial reports, as well as fulfilling a legal obligation to monitor data to ensure subject health and safety.

Subject enrollment

Since the 2004 two-year report, one exposed subject was removed from the study, and 40 new exposed subjects were enrolled. Six of these new subjects were controls who have converted to the AH Mk 1 flight program. Therefore, the study currently has 53 distinct exposed subjects enrolled.

A total of 103 control subjects were included in the first interim report. Of these, six were removed from the study because they were Royal Marine pilots and presented limited access for continuing data collection; and six control subjects converted to the AH Mk 1 flight program. Forty-five new control subjects were enrolled during the most recent two-year period. Therefore, the study currently has 136 distinct control subjects enrolled.

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[1] The collection of data was suspended during the first year of the study due to late delivery of aircraft, during which no Apache flight hours were logged. Hence, this report covers only 4 years of exposure (November 2000 - December 2004) and is referred to as the four-year report.

This four-year report presents an analysis only for those enrolled subjects who have a minimum of 3 years of measured data during the four-year exposure period. Therefore, the current report analyzes data for only seven exposed and 23 control subjects having the requisite number of years of measured data.

Study timeline

Table ES-1 presents the execution status of the full study. The initial phase of the study originally was planned for 1998. However, due to delays in both the initial military airworthiness release of the airframe and the availability of the Full Mission Simulator, the study start was not implemented until 2000. As a result, the first biennial report contained only one year of data for enrolled subjects; correspondingly, the current four-year report includes only 3 years of data.

The original study design anticipated a total of at least 80 exposed and 300 control subjects by the midpoint (end of fifth year) of the study. Considering the one year delay, data collection is in its third year and projected enrollment should be 48 exposed and 180 control subjects. Therefore, the current study enrollment of 53 exposed subjects meets the projection, while the total of 136 control subjects fails to do so.

Table ES-1.
Study timeline.

Phase	Dates	Objective	Execution
ONE	1998 to 2000	Protocol development and approval	Completed 2000
TWO	2000 to 2001	Initial report – Study purpose and scope	Completed 2001
THREE	2000 to 2006	Subject enrollment	Data collection delayed; exposed subject enrollment on target, but control subject enrollment below projection
FOUR	2000 to 2008	Biennial interim reports	
	2000 to 2002	2-year report	Completed 2004
	2003 to 2004	4-year report	Completed 2006
	2005 to 2006	6-year report	Pending
	2007 to 2008	8-year report	Pending
FIVE	2010	Final report	Pending

Methods

A cohort of British Apache AH Mk 1 pilots (exposed group) and a control group of British Army helicopter pilots who fly aircraft other than the Apache AH Mk 1 are being followed over a 10-year period. At yearly intervals, the subjects complete questionnaires and undergo expanded flight physical examinations. The questionnaires address flight experience, vision history, disorientation, neck and back pain, helmet usage, contact lens use, and handedness. The expanded physical examination adds a battery of vision tests designed to assess both monocular and binocular visual performance.

Demographics

The total number of exposed (AH Mk 1) subjects enrolled as of 31 December 2004 (over the period November 2000 to December 2004) is 53. All exposed subjects are male, with a mean age of 35 years, and total flight hours ranging from 410 to 7250, with a mean and median of 2358 and 2000 hours (hr), respectively. The total number of control subjects enrolled over the same period is 136. The control subjects are predominately male (96%), with a mean age of 31 years. The total flight hours for the control group range from 13 to 8400, with a mean and median of 909 and 214 hr, respectively. The exposed subjects have a mean of 116 flight hours using the Apache's monocular IHADSS HMD. The control subjects have a mean of 51 flight hours using night vision goggles (NVGs).

For this longitudinal analysis, the total number of exposed (AH Mk 1) subjects is seven. All are male, with a mean age of 40 years, and total flight hours ranging from 2330 to 7250, with a mean and median of 3746 and 3200 hr, respectively. The total number of control subjects included in this analysis is 23. The control subjects are predominately male (91%), with a mean age of 36 years. The total flight hours for the control group range from 370 to 8400, with a mean and median of 2121 and 1460 hr, respectively. The exposed subjects have a mean of 442 flight hours using the Apache's monocular IHADSS HMD. The control subjects have a mean of 117 total flight hours using NVGs.

Summary

Tables ES-2 and ES-3 summarize the comparison between demographics, visual examination data, and questionnaire responses of the exposed and control groups for major study parameters. In Table ES-2, demographics data are provided for both total subject enrollment and for those subjects analyzed in the current four-year review.

Demographics

For the total study enrollment, the mean age for exposed subjects has decreased from 39 years (two-year review) to 35 years (current), while the mean age for control subjects remained the same at 31 years. Although the difference between exposed and control mean ages decreased, it is still statistically significant ($p < .001$). Likewise, for total flight hours, the mean for exposed subjects decreased from 3720 to 2358 hr, while the mean for control subjects increased slightly from 805 to 909 hr. Although this difference decreased, it also remains statistically significant ($p < .001$). Gender remains predominantly male for both exposed (100%) and control (96%) subjects.

For the subjects included in the four-year analysis, the mean age for exposed subjects is 40 years and 36 years for control subjects. This difference is not statistically significant ($p = .247$). Similarly, the difference between mean total flight hours for exposed (3746 hr) and control (2121 hr) is not statistically significant ($p = .078$). Gender is predominantly male for both exposed (100%) and control (91%). Exposed mean night vision device (IHADSS) flight hours in the AH Mk 1 (442 hr) is significantly different from control NVG flight hours (117 hr) ($p < .001$).

Table ES-2.
Demographics.

Variable	Exposed	Control	Findings
Full study			
Sample size (*N*)	*N* = 53	*N* = 136	
Age	Mean (*M*) = 35 years	*M* = 31 years	Difference statistically significant ($p < .001$)
Gender	Male 100%	Male 96%; Female 4%	
Total flight hours	*M* = 2358 hr Median (*Mdn)* = 2000 hr	*M* = 909 hr *Mdn* = 214 hr	Differences statistically significant ($p < .001$)
Night vision device flight hours	IHADSS *M* = 116 hr *Mdn* = 126 hr	NVG *M* = 51 hr *Mdn* = 6 hr	Differences statistically significant ($p < .001$)
Four-year analysis			
Sample size	*N* = 7	*N* = 23	
Age	*M* = 40 years	*M* = 36 years	Difference not statistically significant ($p = .247$)
Gender	Male 100%	Male 91%; Female 9%	
Total flight hours	*M* = 3746 hr *Mdn* = 3200 hr	*M* = 2121 hr *Mdn* = 1460 hr	Differences not statistically significant ($p = .078$)
Total night vision device flight hours	IHADSS *M* = 442 hr *Mdn* = 379 hr	NVG *M* = 117 hr *Mdn* = 64 hr	Differences statistically significant ($p < .001$)

Vision history

Both sample groups predominately prefer their right eye for sighting tasks. The exposed group has a higher proportion requiring vision correction (43% versus 35%) as compared to the larger control group, but this difference is not statistically significant ($p = .698$). The ratio of percentage of contact lens wearers for the exposed group is 14% compared to 9% for the control group. See Table ES-3.

Visual problems

The most reported visual symptoms *during* flight are disorientation (71%), headache (57%), and visual discomfort (43%) for the exposed group and headache (63%) and disorientation (56%) for the control group. For the shared complaints of headache and disorientation, the differences between the exposed and control groups are not statistically significant ($p = .780$, $p = .467$), respectively. The symptom of afterimages is the most reported for exposed subjects (57%) *after* flight, followed by the symptom of headache (43%). Headache is the most reported symptom for control subjects (48%) *after* flight. The difference in frequency of headaches *after* flight between exposed and control subjects is not statistically significant ($p = 0.818$). The proportion of the exposed group reporting experiencing eye fatigue (to some extent) *during* flight

with the IHADSS HMD is 86%, as compared to 91% for the control group flying with NVGs; this difference is not statistically significant (p = .694).

Of the 22 responding control subjects, 14 (64%) reported experiencing color perception problems after flying with NVGs due to color adaptation. All of these subjects reported a persistent "browned vision" for up to 15 minutes (min) post-flight. Two exposed subjects (29%) reported a similar phenomenon, with one of these two subjects reporting the effects disappearing in less than 15 min post-flight and the other subject reporting the effects disappearing in 1 to 2 hr post-flight. A two-way contingency table analysis was conducted to evaluate whether exposed subjects (29%) had a different proportion of color episodes than control subjects (64%); no significant difference was found (χ^2 = 2.64, p = .104).

Table ES-3.
Executive summary.

Variable	Exposed	Control	Findings
VISION HISTORY			
Vision correction	43% require vision correction (n = 7)	35% require vision correction (n = 23)	Difference not statistically significant (p = .698)
Sighting eye preference	86% right; 14% left; 0% bilateral (n = 7)	61% right; 26% left; 4% bilateral (n = 23)	Difference not significantly significant (p = .723)
Contact lens usage	14% wore contacts (n = 7)	9% wore contacts (n = 23)	Difference not statistically significant (p = .666)
VISUAL PROBLEMS			
Visual symptoms	Disorientation (71%), headache (57%) and visual discomfort (43%) most frequently reported symptoms *during* flight (n = 7)	Headache (63%) and disorientation (56%) most frequently reported symptoms *during* flight (n = 19)	Difference in frequencies of reported headaches and disorientation not statistically significant (p = .780, p = .467)
	Afterimages (57%) and headache (43%) most frequently reported symptoms *after* flight (n = 7)	Headache (48%) most frequently reported symptom *after* flight (n = 23)	Difference in frequency of reported headaches not statistically significant (p = .818)
Eye fatigue	86% reported experiencing eye fatigue (n = 7)	91% reported experiencing eye fatigue (n = 22)	Difference not statistically significant (p = .694)
Color adaptation	29% reported experiencing color episodes (n = 7)	64% reported experiencing color episodes (n = 22)	Difference not statistically significant (p = .104)
DISORIENTATION			
Episodes of disorientation	57% reported experiencing disorientation (n = 7)	26% reported experiencing disorientation (n = 23)	Difference not statistically significant (p = .127)
HANDEDNESS			
Edinburgh Handedness Inventory (EHI)	86% right; 14% left Mean EHI = +66 (n = 7)	87% right; 13% left Mean EHI = +63 (n = 23)	Differences in proportion and EHI scores not statistically significant (p = .933, p = .922)

Table ES-3 (continued).
Executive summary.

Variable	Exposed	Control	Findings
EYE EXAMINATION			
Refractive error (spherical equivalent)	Right eye -0.75D; Left eye -0.68D (*n* = 5)	Right eye +0.01D; Left eye +0.07D (*n* = 19)	Differences not statistically significant (Right, *p* = .085; Left, *p* = .075)
	Within-subject Right: -0.34D (pre) and -0.52D (post) Left: -0.39D (pre) and -0.43D (post)		Paired-samples *t-test*: Differences not statistically significant (Right, *p* = .221; Left, *p* = .747)
Bailey-Lovie high contrast visual acuity	Right 0.13 logMAR; Left 0.13 logMAR (*n* = 7)	Right 0.08 logMAR; Left 0.10 logMAR (*n* = 23)	Differences not statistically significant (Right, p = .06; Left, p = .23)
	Within-subject Right: 0.24 logMAR (pre) and 0.13 logMAR (post) Left: 0.19 logMAR (pre) and 0.13 logMAR (post)		Paired-samples *t-test*: Differences statistically significant (Right, *p* = .04; Left, *p* < .001); however, differences imply improved performance
Bailey-Lovie low contrast visual acuity	Right 0.43 logMAR; Left 0.43 logMAR (*n* = 7)	Right 0.45 logMAR; Left 0.41 logMAR (*n* = 13)	Differences not statistically significant (Right, *p* = .42; Left, *p* = .36)
	Within-subject Right: 0.44 logMAR (pre) and 0.43 logMAR (post) Left: 0.45 logMAR (pre) and 0.43 logMAR (post)		Paired-samples *t-test*: Differences not statistically significant (Right, *p* = 0.57; Left, *p* = 0.42)
Small letter contrast	Right 0.92 logCS; Left 0.93 logCS (*n* = 7)	Right 1.01 logCS; Left 0.99 logCS (*n* = 21)	Differences not statistically significant (Right, *p* = .15; Left, *p* = .28)
	Within-subject Right: 0.80 logCS (pre) and 0.92 logCS (post) Left: 0.80 logCS (pre) and 0.93 logCS (post)		Paired-samples *t-test*: Differences not statistically significant (Right, *p* = .15; Left, *p* = .20)
Depth perception	20” arc - 14% 25” arc - 57% 30” arc - 29% (*n* = 7)	20” arc - 9% 25” arc - 70% 30” arc - 17% 50” arc - 4% (*n* = 23)	Difference not statistically different (*p* = .728)

Table ES-3 (continued).
Executive summary.

Variable	Exposed	Control	Findings
Color perception	Right 63.4; Left 64.8 (*n* = 7)	Right 65.1; Left 65.9 (*n* = 23)	Differences not statistically significant (Right, *p* = .842; Left, *p* =.911)
	Within-subject Initial: -4.66 Final: 1.03		Independent-samples *t-test* (IOD metric): Differences not statistically significant (*p* = .903)
Accommodation (20 to 29 yr old)	N/A	Right 6.5D; Left 6.6D (*n* = 5)	N/A
Accommodation (30 to 39 yr old)	Right 5.5D; Left 5.7D (*n* = 4)	Right 6.3D; Left 6.0D (*n* = 11)	Differences not statistically significant (Right, *p* = .53; Left, *p* = .72)
Accommodation (40 to 49 yr old)	Right 3.3D; Left 3.4D (*n* = 3)	Right 3.8D; Left 4.1D (*n* = 5)	Differences not statistically significant (Right, *p* = .70; Left, *p* = .57)
Accommodation	Within-subject Initial: -0.38 Final: 0.09		Independent-samples *t-test* (IOD metric): Differences not statistically significant (*p* = .107)
Eye muscle balance (distance)	100% orthotropia; 100% esophoria; 71% hyperphoria (*n* = 7)	100% orthotropia; 85% esophoria; 15% exophoria; 50% hyperphoria (*n* = 20)	Difference not statistically significant (*p* = .28)
Eye muscle balance (near)	100% orthotropia; 100% esophoria; 85% hyperphoria (*n* = 7)	100% orthotropia; 80% esophoria; 15% exophoria; 65% hyperphoria (*n* = 20)	Difference not statistically significant (*p* = .21)
Eye preference	43% right; 57% left (*n* = 7)	65% right; 35% left (*n* = 23)	Difference not statistically significant (*p* = .290)
	Within-subject 57% switched reported dominant eye		

Disorientation

Episodes of spatial disorientation, defined as a failure to perceive correctly one's position, motion or attitude with respect to the Earth's surface or the acceleration due to gravity, are reported by 57% of the exposed group and by 26% of the control group, a difference that is not statistically significant (*p* = .127).

Handedness

As measured by absolute and relative scores, handedness for both the exposed and control groups is predominately right, 86% and 87%, respectively). Mean relative handedness scores, as measured by the Edinburgh Handedness Inventory (EHI) are: exposed = +66; control = +63.

The difference in proportions and relative EHI scores are not statistically significant (p = .933, p = .922, respectively).

<u>Eye examination</u>

The eye examination data show no statistically significant differences between exposed and control groups for any of the nine visual tests: mean refractive error, high and low contrast visual acuity, small letter contrast, depth perception, color perception, accommodative power, near and far eye muscle balance, and eye preference.

Refractive error

Refractive error is measured using spherical equivalent. For exposed subjects, the means for spherical equivalent refractive error are -0.75 and -0.68 dioptres for the right and left eyes, respectively. For control subjects, the means for spherical equivalent refractive error are +0.01 and +0.07 dioptres for the right and left eyes, respectively. The differences between these means are not significant (right eyes, p = .085; left eyes, p = .075). These numerical differences are most likely due to the difference in age of the two groups, in keeping with the trend toward increasing myopia with age.

A paired-samples *t-test* was conducted for the seven exposed subjects to evaluate whether there is a significant difference in spherical equivalent refractive error scores between the first and last measured scores for each eye for exposed subjects. The results indicate that the mean for the first measurement for the right eye (M = -0.34, standard deviation [*SD*] = 1.23) is not statistically significantly different from the mean for the last measurement (M = -0.52, *SD* = 1.22), $t(6) = 1.37$, p = .221. The average exposure time between first and last measurements is 2.6 years.

For the left eye, the first measurement (M = -0.39, *SD* = 1.00) is not statistically significantly different from the mean for the last measurement (M = -0.43, *SD* = 1.02), $t(6) = 0.34$, p = .747. The average exposure time between first and last measurements is 2.6 years. The mean difference in dioptres is 0.04 between the two scores for the left eye, and there is considerable overlap in the distributions for the two scores.

Bailey-Lovie high contrast visual acuity

For both groups, letters missed on the high contrast visual acuity chart are converted to a logMAR score for statistical/analytical purposes. For exposed subjects, the means for right and left eyes are each 0.13 logMAR. For control subjects, the means for right and left eyes are 0.08 and 0.10 logMAR, respectively. Differences between these means are not statistically significant (right, p = .06; left, p = .23).

Paired-sample *t-test*s were used to determine if there is a statistically significant difference between the first and last measured data values of each exposed subject. The initial and final means for the right eye are 0.24 and 0.13 logMAR, respectively. For the left eye, the initial and final means are 0.19 and 0.13 logMAR, respectively. Both differences are statistically

significant (right, $p = .04$; left $p < .001$). Although the differences are significant, they are indicative of improved performance, i.e., a greater number of subjects having a more appropriate spectacle correction.

Bailey-Love low contrast visual acuity

For both groups, letters missed on the low contrast visual acuity chart were converted to a logMAR score for statistical/analytical purposes. For exposed subjects, the means for right and left eyes are each 0.43 logMAR. For control subjects, the means for right eye is 0.45 logMAR and for the left eyes 0.41 logMAR. Differences between these means are not statistically significant (right, $p = .42$; left, $p = .36$).

Paired-sample *t-test*s were used to determine if there was a statistically significant difference between the first and last available measured data values for each exposed subject. The initial and final means for the right eye are 0.44 and 0.43 logMAR, respectively. For the left eye, the initial and final means are 0.45 and 0.43 logMAR, respectively. Neither difference is statistically significant (right, $p = .57$; left, $p = .42$).

Small letter contrast sensitivity

For both groups, letters missed on the small letter contrast chart were converted to a logCS score for statistical/analytical purposes. For exposed subjects, the means for right and left eyes are 0.92 and 0.93 logCS, respectively. For control subjects, the means for right and left eyes are 1.01 and 0.99 logCS, respectively. The differences between these means are not statistically significant (right, $p = .15$; left, $p = .28$).

Paired-sample *t-test*s were used to determine if there was a statistically significant difference between the first and last measured data values of each exposed subject. The initial and final means for the right eye are 0.80 and 0.92 logCS, respectively. For the left eye, the initial and final means are 0.80 and 0.93 logCS, respectively. Neither difference is statistically significant (right, $p = .15$; left $p = .20$).

Depth perception

Depth perception was measured in seconds of arc (″). For exposed subjects, 57% measured 25″, 29% measured 30″, and 14% measured 20″. For control subjects, 70% measured 25″, 17% measured 30″, 9% measured 20″, and 4% measured 50″. The difference in these distributions is not statistically significant ($p = .728$).

Color perception

Color perception scores were measured using the L'Anthony desaturated D-15 hue test. For exposed subjects, the means are 63.4 and 64.8 for right and left eyes, respectively. For control subjects, the means are 65.1 and 65.9 for right and left eyes, respectively. Neither difference is statistically significant (right, $p = .842$; left, $p = .911$).

Accommodation

Exposed and control subjects were broken into age groups based on decade increments. For exposed subjects in the 30 to 39 year age group, the means for true accommodation are 5.5 and 5.7 dioptres for the right and left eyes, respectively. For control subjects in this same age group, the means are 6.3 and 6.0 dioptres for right and left eyes, respectively. Neither difference is statistically significant (right, $p = .53$; left, $p = .72$). For exposed subjects in the 40 to 49 year age group, the means for true accommodation are 3.3 and 3.4 dioptres for the right and left eyes, respectively. For control subjects in this same age group, the means are 3.8 and 4.1 dioptres for right and left eyes, respectively. Neither difference is statistically significant (right, $p = .70$; left, $p = .72$).

A paired-samples *t-test* was conducted to evaluate whether there is a significant difference in accommodative power between the first and last measured values for each eye for exposed subjects. The results indicate that the mean for the first measurements for the right eye ($M = 8.30$, $SD = 4.24$) is not statistically significantly different from the mean for the last measurements ($M = 4.68$, $SD = 1.63$), $t(6) = 2.38$, $p = .055$. Similarly for the left eye, the first measurements ($M = 7.92$, $SD = 4.18$) are not statistically significantly different from the last measurements ($M = 4.58$, $SD = 1.50$), $t(6) = 2.14$, $p = .076$.

An alternative investigation is to compare left versus right eye scores using the IOD metric. The mean IOD scores were -0.38 and 0.09 for initial and final measurements, respectively. Negative IOD scores imply that the right eye value was larger than that for the left eye. When tested via an independent-samples *t-test*, the two means were not found to be statistically different, $p = .107$.

Eye muscle balance

As measured with the Optec® 2000 Vision Tester, 100% of exposed and control subjects were determined to exhibit orthotropia at <u>distance</u> conditions (indicates lack of strabismus). One-hundred percent of exposed subjects are esophoric and 71% were hyperphoric. Eighty-five percent of control subjects are esophoric, 15% are exophoric, and 50 % are hyperphoric. The difference in the ratios of these percentages is not statistically significant ($p = .28$). One-hundred percent of exposed and control subjects were determined to exhibit orthotropia at <u>near</u> conditions. One-hundred percent of exposed subjects are esophoric and 85% are hyperphoric. Eighty percent of control subjects are esophoric, 15% are exophoric, and 65 % are hyperphoric. The difference in the ratios of these percentages is not statistically significant ($p = .21$).

Eye preference

Using the “hole” test, eye preference was measured for all exposed and control subjects. Fifty-seven percent of exposed subjects preferred their left eye, while 65% of control subjects preferred their right eye. This difference in proportions is not statistically significant ($p = .290$).

Over the entire reporting period (although one of these subjects was only measured for three years), three of the seven exposed subjects present as having right-eye sighting preference.

Another three subjects demonstrate a reversal in the sighting preference eye, switching from right- to left-eye preference, for the last examination. The last subject, having data only for 3 years, presents findings that alternated between left-, right-, and then back to left-eye dominance. Therefore, based on the last examination data available for each subject, four out of the seven exposed subjects (57%) are found to have switched eye preference for the tested sighting task.

Conclusions

The original study design called for a projection of 80 exposed and 300 control subjects by the midpoint (end of fifth year) of the study. Considering the one year delay, data collection is in its third year and enrollment was projected to be 48 exposed and 180 control subjects. The current study enrollment of 53 exposed subjects meets the projection; while the total of 136 control subjects fails to do so.

Both between- and within-subject data analyses failed to find any statistically significant differences in performance on the visual tests for exposed and control subjects. Of all the visual parameters evaluated over the first 3 years of collected data, only measures of preferred eye showed any detectable change, and this change manifested itself only during the last measurement cycle. Its impact is unknown at this time.

At this phase in the study, there is no evidence that the prolonged use of the monocular IHADSS HMD has produced any meaningful differential vision changes between the two eyes. As the study progresses, we will continue to identify any trends in visual performance between eyes that may support or refute the presence of these differential changes.

Recommendations

As the study progresses towards its midpoint, it is recommended that the following issues be addressed:

a. Study administrators must take appropriate actions to increase control sample size.

b. A continuing common problem associated with this study is maintaining stringent oversight of data collection. A small percentage of study questionnaires were not completed, resulting in missing data values. A tighter oversight of questionnaire completion is recommended.

c. A high percentage of exposed subjects require vision correction. It is recommended, where appropriate, that vision tests be conducted with and without vision correction.

d. Particular attention must be paid to ensuring that the procedure used to measure eye preference be methodical from subject to subject.

Preface

This is the second interim (four-year) report for the study titled *The Effect of a Monocular Helmet-Mounted Display on Aircrew Health: A Cohort Study of Apache AH Mk 1 Pilots*.[2] The principal aim of this occupational health study is to determine if the use of the monocular helmet-mounted display in the British Army's Apache AH Mk 1 attack helicopter has any long-term effect on visual performance. Additional information concerning other unique problems of the Apache AH Mk 1 aircrew is elicited as a secondary objective. This study is a collaborative effort between the British Army and the U.S. Army, and is conducted under the auspices of The Technical Cooperative Program, Subgroup U, Technical Panel 7, (Human Factors in the Aviation Environment). Scientific and Human Use protocols were approved by responsible UK and USAARL parties within the period December 1999 to January 2000. An initial report describing the study's protocol, methodology, development and initial execution phase was published as USAARL Report No. 2002-04. The first interim (two-year) report was published as USAARL Report No. 2004-18. This second interim report covers the period of January 2000 to December 2004 and documents the data for 30 (exposed, n = 7; control, n = 23) subject pilots collected from the period 17 November 2000 to 31 December 2004. Additional interim reports will be provided in approximate two-year intervals. A final technical report will be published in approximately 10 years time from the start of the study (approximately year 2010).

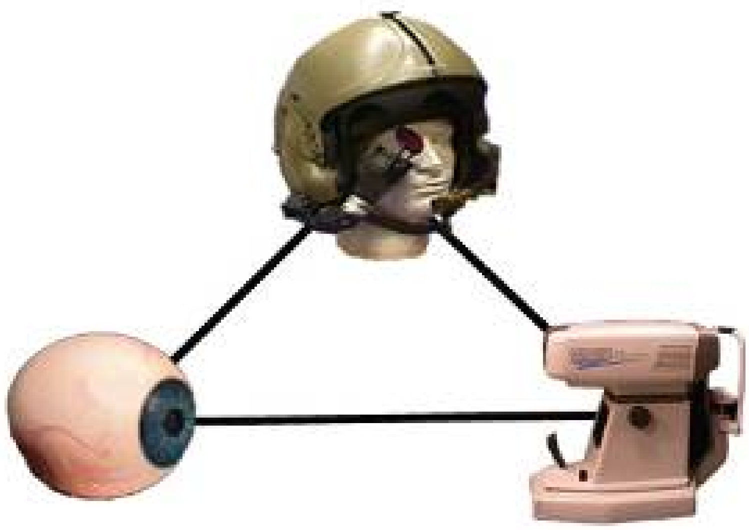

Figure ES. The Apache AH Mk 1 cohort study logo.

[2] The collection of data was suspended during the first year of the study due to late delivery of aircraft, during which no Apache flight hours were logged. Hence, this report covers only 4 years of exposure (November 2000 - December 2004) and is referred to the four-year report.

Acknowledgments

This work is supported by the United States Army Aeromedical Research Laboratory (USAARL), Fort Rucker, Alabama; the Ministry of Defence – British Army Air Corps, UK; and the Drummond Trust Foundation, administered by the Military Assistant To The Director General Army Medical Services. Army Medical Directorate, Keogh Barracks, Aldershot, Hampshire, UK.

The ambitious scope of this study has necessitated a large effort by a great number of individuals over an extended time period. This list of contributors will continue to grow. The role and contributions of the major contributors are as follows (in alphabetical order) and reflect the titles of the individuals at the time that they became a contributor to the study:

- LTC Mark S. Adams, OBE, L/RAMC, Consultant Advisor in Aviation Medicine, Headquarters Director Army Aviation, Middle Wallop, UK, serves as UK study leader (FY07-present).

- COL (Retired) Malcolm G. Braithwaite, OBE, L/RAMC, Colonel Occupational Medicine, HQ Army Training and Recruiting Agency, Upavon, Wiltshire, UK, co-authored the original study protocol and served as UK study leader (FY98-05).

- MAJ Jeffery M. Cleland, OD, Branch Chief, Visual Sciences Branch, Aircrew Health and Performance Division, U.S. Army Aeromedical Research Laboratory, Fort Rucker, Alabama, US, served as U.S. vision consultant to study (FY05).

- COL (Retired) John S. Crowley, MD, MPH, U.S. Army Medical Corps, Science Program Director, U.S. Army Aeromedical Research Laboratory, Fort Rucker, Alabama, US, served as Aeromedical Exchange Officer to the UK and co-authored the original study protocol (FY98-99).

- LTC (Retired) Allison J. Eke, RAMC, Consultant in Aviation Medicine, formerly at Defence Evaluation and Research Agency, Centre for Human Sciences, Farnborough, UK, participated in development of study protocol (FY98-99).

- Eric S. Harris, Student Researcher, Aircrew Health and Performance Division, U.S. Army Aeromedical Research Laboratory, Fort Rucker, Alabama, US, performed data entry and extensive analysis for two-year and four-year reports (FY04-05).

- COL Keith L. Hiatt, MD, MPH, U.S. Army Medical Corps, Aerospace Medicine Consultant - Apache Systems, Headquarters Director Army Aviation, Middle Wallop, UK, served as the Aeromedical Exchange Officer to UK and study's initial principal investigator for period of FY00-02.

- Melissa L. Isaak, BS, MS, Student Researcher, Aircrew Health and Performance Division, U.S. Army Aeromedical Research Laboratory, Fort Rucker, Alabama, US, performed data entry and extensive analysis for the two-year report (FY00-02).

- LTC Ronald P. King, MD, MPH, U.S. Army Medical Corps, Aerospace Medicine Consultant - Apache Systems, Headquarters Director Army Aviation, Middle Wallop, UK, was the Aeromedical Exchange Officer to UK and served as the study's current principal investigator for the period FY02-04.

- SPC Lisa J. Lewis, BS, Research Technician, Aircrew Health and Performance Division, U.S. Army Aeromedical Research Laboratory, Fort Rucker, Alabama, US, has performed database entry and analysis for two-year report (FY00-02).

- LTC (Retired) Corina van de Pol, OD, PhD, U.S. Army Aeromedical Research Laboratory, Fort Rucker, Alabama, US, served as US vision consultant to study (FY00-05).

- Daniel J. Ranchino, BS, Computer Specialist, Research Support Division, U.S. Army Aeromedical Research Laboratory, Fort Rucker, Alabama, US, developed architecture for and maintains study database (FY02).

- Clarence E. Rash, BS, MS, Research Physicist, Sensory Research Division, U.S. Army Aeromedical Research Laboratory, Fort Rucker, Alabama, US, developed visual test battery and serves as US technical coordinator (FY00-present).

- LTC William K. Statz, DO, MPH, U.S. Army Medical Corps, Formerly at DERA Centre for Human Sciences, Farnborough, UK, participated in development of study protocol as former Aeromedical Exchange Officer to UK (FY98-99).

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Introduction

As of December 2004, the British government has purchased 67 Apache AH Mk 1 attack helicopters (formerly identified as the WAH-64). The Apache AH Mk 1 is the latest version of the AH-64A "Apache" helicopter flown extensively by the U.S. Army, and it incorporates many significant improvements (Figure 1). Among these are fire-control radar, improved weapons processors, a glass cockpit, improved data modem, and a multitude of engineering enhancements to overall system architecture and components (Sale and Lund, 1993). This acquisition program is considered an "off-the-shelf" buy, and in many respects, the Apache AH Mk 1 is similar to the Apache Longbow AH-64D helicopter being acquired by the U.S. Army.

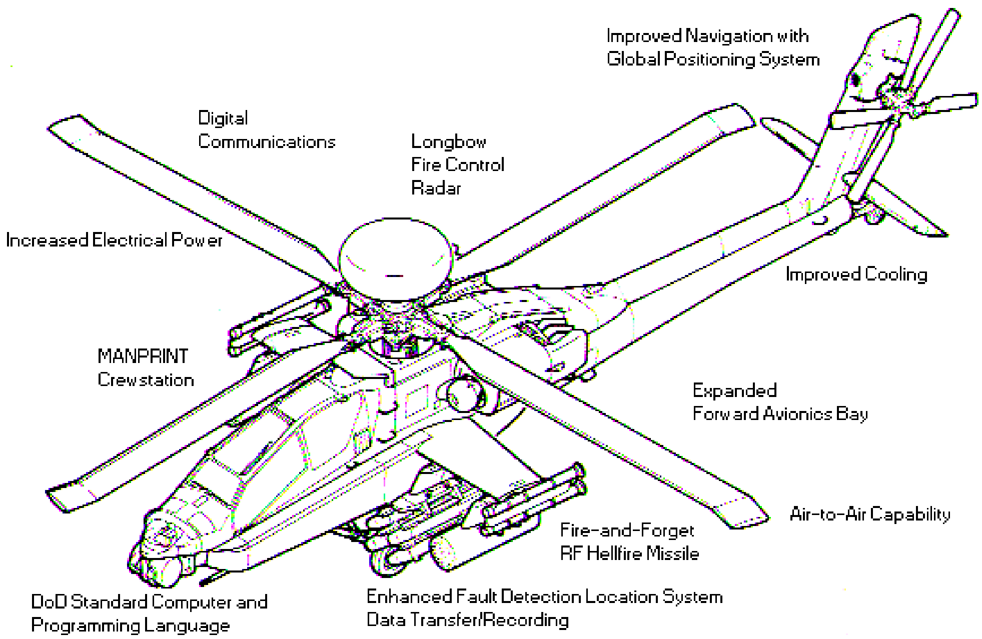

Figure 1. Features of the Westland Apache AH Mk 1, similar to the Boeing Longbow AH-64D (Sale and Lund, 1993).

The protective flight helmet used to date by AH-64A pilots is the Integrated Helmet and Display Sighting System (IHADSS) (Figure 2) (Rash and Martin, 1988). The IHADSS provides sensor video and/or symbology to each crewmember via a helmet display unit (HDU). The HDU contains a 1-inch (in) diameter cathode ray tube (CRT) attached to the right side of the helmet, positioning a combiner lens directly in front of the pilot's right eye. When in use, the HDU usually rests on the pilot's right maxilla/zygomatic arch (right cheekbone); when not needed, it can be rotated away from the face.

The sensor video imagery presented by the IHADSS can originate from either of two thermal sensors mounted on the nose of the aircraft. Pilotage imagery is provided by the Pilot's Night Vision System (PNVS); targeting imagery is provided by the Target Acquisition and Designation System (TADS).

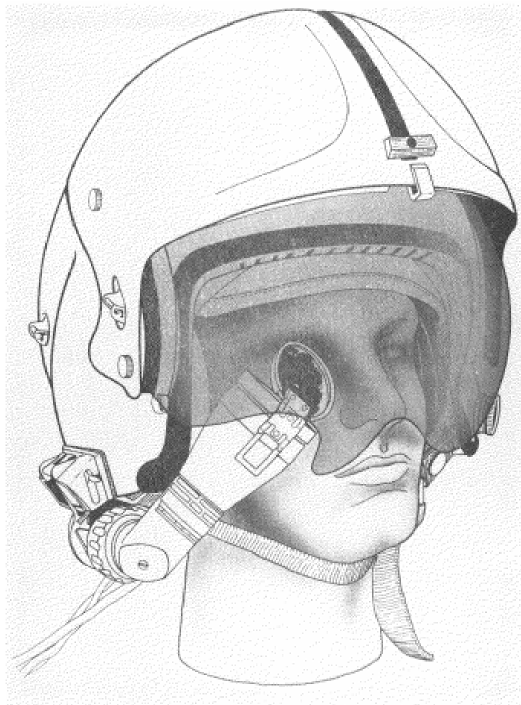

Figure 2. The AH-64 Integrated Helmet and Display Sighting System (IHADSS) (Rash and Martin, 1988).

The Apache pilot's primary source of visual information about the aircraft's state and the outside environment is the HDU. Compelling the aviator to rely on a degraded unnatural view of the world, which is provided only to the right eye, has been noted to cause psychological and physiological problems for many Apache pilots (Behar et al., 1990; Rash and Martin, 1988). Experience has shown that these problems can be generally overcome with training. However, there are residual long-term concerns that have not been completely investigated.

The principal aim of this occupational health study is to determine if the use of the monocular helmet-mounted display (HMD) in the British Army's Apache AH Mk 1 attack helicopter has any long-term effect on visual performance. All British pilots not flying the AH Mk 1 use a version of the binocular image-intensification-based night vision goggles (NVGs). An initial report described the study's protocol, methodology, development and initial execution phase in detail (Hiatt et al., 2002). A two-year interim report (Rash et al., 2004) documented the progress of the study during the period January 2000 to May 2002. It presented the baseline data for 117 subject pilots (exposed, n = 14; controls, n = 103) enrolled in the study from the period 17 November 2000 to 23 May 2002. The report herein documents progress during the five-year period January 2000 to December 2004 (four-year exposure period of November 2000 – December 2004). It presents within- and between-subject analyses for seven exposed and 23 control subjects for whom a minimum of 3 years of data have been collected. Only vision and vision-related data are reported herein. Separate reports will document supplementary data in the areas of neck and back pain and helmet usage.

Study design

General

A cohort of British Apache AH Mk 1 pilots (exposed group) and a control group of British Army helicopter pilots who do not fly the Apache AH Mk 1 are being followed over a 10-year period. At yearly intervals, the subjects complete questionnaires and undergo expanded flight physical examinations. The questionnaires address flight experience, vision history, disorientation, neck and back pain, helmet usage, contact lens use, and handedness. The expanded physical examination consists of a battery of vision tests designed to assess both monocular and binocular visual performance. The rate of change in physiological state and symptomatology will then be compared between the control and exposed groups.

Exposed group

All British Army pilots scheduled for conversion to the Apache AH Mk 1 have been recruited as subjects. Fourteen exposed subjects were enrolled during the first 2 years of the study; one subject was removed and 40 additional exposed subjects were enrolled during the second 2 years of the study, bringing the total exposed enrollment to 53 subjects (including six subjects who converted from control to exposed subject). The original study design anticipated a total of at least 80 exposed subjects by the midpoint (end of fifth year) of the study. Considering the one year delay, data collection is in its third year and projected enrollment should be 48 subjects. Therefore, the current study enrollment of 53 exposed subjects meets the projection.

Control group

All British Army pilots actively flying helicopters other than the Apache have been recruited as control subjects. A total of 103 control subjects were enrolled during the first 2 years of the study; 45 additional control subjects were enrolled during the second 2 years of the study, while 12 were removed due to limited access or conversion to the AH Mk 1 flight program, bringing the total control enrollment to 136 subjects. The original study design anticipated a total of at least 300 control subjects by the midpoint (end of fifth year) of the study. Considering the one year delay, data collection is in its third year and projected enrollment should be 180 control subjects. Therefore, the current study enrollment of 136 control subjects fails to meet this projection.

It should be noted that the study is designed for cross-over of control group individuals receiving Apache transition. For example, control group members who are selected for training as Apache AH Mk 1 pilots will be recruited for the Apache exposed group, and “disenrolled” from the control group. If they consent, their most recent data as a control will be considered their baseline data as an Apache subject. However, aviators leaving the Apache airframe are completely disenrolled from the study.

Timeline

The study was initially delayed in its execution due to a number of factors. The primary factors were delays in both the initial military airworthiness release of the airframe and the delivery of the Apache Full Mission Simulator, which directly affected the training program. The timeline and current status of the study is provided in Table 1.

Table 1.
Study timeline.

Phase	Dates	Objective	Execution
ONE	1998 to 2000	Protocol development and approval	Completed 2000
TWO	2000 to 2001	Initial report – Study purpose and scope	Completed 2001
THREE	2000 to 2006	Subject enrollment	Data collection delayed; exposed subject enrollment on target, but control subject enrollment below projection
FOUR	2000 to 2008	Biennial interim reports	
	2000 to 2002	2-year report	Completed 2004
	2003 to 2004	4-year report	Completed 2006
	2005 to 2006	6-year report	Pending
	2007 to 2008	8-year report	Pending
FIVE	2010	Final report	Pending

Ethical considerations and safety

Medical screening

Army pilots awarded an unrestricted flying medical category (A1 or A2) at their annual aircrew medical examination have been deemed medically qualified to participate in this study. No further medical screening is required. All subjects have the objectives and procedures of the study explained to them, and are encouraged to ask questions. If willing to participate, they are asked to sign a consent form, which is kept on file. They are completely free to withdraw from the study at any time.

Confidentiality

All subjects have been assigned a number that is used to identify their data. No individual has been identified by name in this publication or will be identified by name in any ensuing publication or presentation.

Hazards and precautions

All tests performed on subjects in this study are free from discomfort or risk of injury, other than those associated with normal operational flight. Similar or identical tests are part of the existing annual aircrew medical examination. No specific precautions are necessary as there are no significant hazards or risks to the subjects. Trained medical professionals who have been specifically briefed as to the study methods and objectives conduct all testing.

Limits

If the subject requests, or if the medical or scientific supervisors determine it necessary, the subject's participation in the study has been terminated. All data obtained prior to "disenrollment" will be eligible for inclusion in the analysis. Other reasons for termination are: 1) subject ceases to fly helicopters for a period longer than 2 years, 2) subject leaves military service, or 3) an exposed subject leaves the AH Mk 1 flight program.

Medical responsibility

A supervising medical officer has provided medical oversight during the study. As there are no safety or medical risks to the subjects, no formal medical monitor is necessary. The supervising medical officer was one of the following: CA Avn Med, HQ DAAvn or U.S. Army Consultant Aerospace Medicine, HQ DAAvn.

Materials and methods

The study consists of a number of optometric and anthropometric measurements (objective measures), performed as part of an expanded, annual flight physical examination, as well as a series of questionnaires (subjective and self-reported measures) that are administered to both groups.

Visual measures

All tests of visual performance are conducted monocularly and binocularly in all cases except where impractical (e.g., in eye dominance testing). Visual acuity and contrast sensitivity are measured with correction (spectacles or contact lenses), if used. A summary of all visual test measures is provided in Table 2. A full description of tests has been presented in Hiatt et al. (2002).

Subjective measures

Upon entry to the study, each subject completes a subject consent form, a demographic questionnaire, and either an annual questionnaire for non-Apache (control) pilots or for Apache (exposed) pilots. These latter questionnaires address flight experience, vision history, disorientation, neck and back pain (not included in this report), and helmet usage (not included in this report). For those individuals wearing contact lenses, an additional questionnaire is provided. Finally, all subjects complete the Edinburgh Handedness Inventory (Oldfield, 1971), a 10-item measure of laterality. These questionnaires may be reviewed in the two-year report (Rash et al., 2004).

Table 2.
Summary of visual test measures.

Test	Dependent measure	Units
Visual acuity (High-Low contrast)	Log of minimal angle resolved (logMAR); smallest readable Letter	Arc seconds
Refractive error (Autorefractor)	Spherical and cylindrical power	Dioptres
Contrast sensitivity	Lowest contrast letters readable	LogCS
Color vision	Selected sequence of color tabs	Color error score
Eye dominance	Eye determined to be 'sighting'	None
Eye muscle balance (Stereo Optical Device)	Horizontal and vertical phorias	Prism dioptres
Depth perception (Stereo circles)	Smallest detectable disparity	Arc seconds
Nearpoint of accommodation	Shortest distance to read fine print	Centimetres (converted to Dioptres)
Questionnaire	Various	N/A

Analysis approach

This study is considered to be longitudinal in nature. Longitudinal data result from observing subjects on a number of variables over time (Bijleveld et al., 1998). This description implies a repeated measures design, i.e., observations are made on a certain number of occasions. One rationale for a longitudinal study is to investigate change in one or more variables over time. In this study, there are multiple variables associated with visual performance, e.g., visual acuity, color discrimination, eye dominance, contrast sensitivity, etc.

Longitudinal studies can examine both intraindividual (within-subject) and interindividual (between-subject) changes over time. Detecting the presence of intraindividual changes in these

variables for AH Mk 1 pilots exposed to long-term use of the monocular HMD is the overall goal of this study. Interindividual changes are examined by comparing data for AH Mk 1 pilots to a control sample of non-AH Mk 1 military pilots. A general assumption of longitudinal studies is that observations over time are equally spaced. While access to pilots often is complicated by numerous factors, the study attempts to collect subject data on a yearly basis. To a reasonable extent, this was achieved; however, actual measurement periods ranged from 9 to 15 months.

One assumption of standard statistical tests commonly applied to longitudinal data is independence, i.e., subsequent measurements are not dependent upon previous measurements. In fact, in this study, successive measurements are serially dependent, which invalidates many statistical methods. This issue is addressed in this analysis by the implementation of repeated-measures analysis of variance (ANOVA) techniques and through the use of paired-sample *t-test*s, based on the first and last available data points for each subject. The Statistical Programs for the Social Sciences (SPSS) software package is used for all analyses.

A second issue associated with these data collected within this study is that of random sampling. Longitudinal studies often are unable to achieve random sampling due to their inherent nature. A special consideration is for the exposed subject group of AH Mk 1 pilots. This group is extremely limited in number, estimated to be 75 as of December 2004, and geographically scattered, resulting in some difficulty in obtaining measurement data for each year. Therefore, the exposed sample is influenced by availability.

Between-subject analyses were performed first. For some test parameters, if no statistically significant difference was found between exposed and control groups, within-subject analyses were not performed. However, where deemed appropriate and especially for eye examination data, either repeated-measures ANOVAs or paired-samples *t-test*s were performed, where the first and last available data values for each subject over individual exposure periods served as the *t-test* data pairs. The p-value was set at the $p < .05$ level.

Data management

As the data collected for the study are medical in nature and include biographical data, they are being treated as any other medical record with regard to confidentiality. A secure long-term storage system for paper and electronic copies of the data has been identified as being essential. To date, initial data collection has been via paper copy. Data then has been entered into a Microsoft Access® database. A full description of the database management system is available in Hiatt et al. (2002).

Demographics

Full study

From the two-year analysis to the four-year analysis, the exposed enrollment increased from 14 to 53 subjects. During this same period, the control enrollment increased from 103 to 136 subjects. The original study design anticipated a total of at least 80 exposed and 300 control subjects by the midpoint (end of fifth year) of the study. Considering the one year delay, data collection is in its third year, and projected enrollment should be 48 exposed and 180 control subjects. Therefore, the current study enrollment of 53 exposed subjects meets the projection, while the total of 136 control subjects fails to do so.

Over this same time period, the mean age of the control subjects (31 years) remained the same, while the mean age for exposed subjects decreased from 39 years to 35 years. This difference between exposed and control mean ages, although decreased, was still statistically significant ($p < .001$). Similarly, for total flight hours, the mean for control subjects increased slightly from 805 hr to 909 hr, while the mean for exposed subjects decreased from 3720 hr to 2358 hr. Although this difference in means decreased, the difference was still statistically significant ($p < .001$).

Four-year sample

The total number of control (non-Apache) subjects enrolled as of 31 December 2004 and included in this longitudinal analysis was 23; all were enrolled during the period February 2001 to December 2004. Control subjects ranged in age from 23 to 51 years with a mean and median each of 36 years. The breakdown of control subjects by flight status was Line Pilot (39%), Qualified Helicopter Instructors (QHI) (29%), and other (22%). The gender breakdown for control subjects was 21 males (91%) and 2 females (9%).

The total flight hours for the control group ranged from 370 to 8400, with a mean and median of 2121 and 1460 hr, respectively. Within the year prior to this analysis, total flight hours ranged from 0 to 340, with a mean and median of 180 and 200 hr, respectively.

The total number of exposed subjects enrolled as of 31 December 2004 and included in this longitudinal analysis was seven; all were enrolled during the period November 2000 to December 2004. Exposed subjects ranged in age from 35 to 48 years, with a mean and median of 40 and 39 years, respectively. Six (86%) of the exposed subjects were QHI; one (14%) was a Line Pilot. All seven (100%) exposed subjects were male.

The total flight hours for the exposed group ranged from 2330 to 7250, with a mean and median of 3746 and 3200 hr, respectively. Within the year prior to this analysis, total flight hours ranged from 70 to 300 with a mean and median of 196 and 200, respectively. Total flight hours in the Apache ranged from 150 to 820, with a mean and median of 446 and 450 hr, respectively. Flight time using the IHADSS had a mean and median of 442 and 379 hr, respectively.

When the two subject groups were compared, both groups were predominately male (exposed = 100% male; control = 91% male). The exposed group was older (*M* = 40 years vs. *M* = 36 years for control group), but this difference was not statistically significant ($p = .247$). There also was a lack of significance between total flight hours, where the mean exposed total flight hours was 3746, versus 2121 hr for control subjects ($p = .078$). However, the difference between the total number of flights hours using the respective night vision devices was statistically significant (IHADSS = 442 hr vs. NVG = 117 hr, $p < .001$).

Data and between-subject analyses

The following sections present those data considered most pertinent to the primary design goal of the study, i.e., an investigation of visual effects. Between-subject analyses were conducted for seven exposed and 23 control subjects for whom a minimum of three years of data have been collected. (Note: Delays between the start of the study and first data collection resulted in only 3 years of data being acquired in the first 4 years.) Only vision and vision-related data are reported herein. Separate reports will document supplementary data in the areas of neck/back pain and helmet usage. Except where noted, percentages in the sections below are based on the proportion of subjects who provided responses to the individual questions or for whom visual test measurements were obtained. To facilitate linking presented data to the various questions in the questionnaires, data values presented in the following sections are referenced to the associated question number (see Hiatt et al., 2002 or Rash et al., 2004 for copies of the questionnaires).

Annual questionnaire

Vision history

Vision correction

Of the 23 control subjects, 35% ($n = 8$) indicated having been prescribed vision correction (Question 10), with flying and reading correction being the most reported reasons. Nine percent ($n = 2$) indicated that they wore contact lenses at the time of the study (Question 11); 26% ($n = 6$) wore spectacles. The ratio of contact lens to spectacle wearers for respondents requiring vision correction was 1:3.

Of the seven exposed subjects, 43% ($n = 3$) indicated having been prescribed vision correction (Question 10). Fourteen percent ($n = 1$) of respondents indicated wearing contact lenses at the time of the study (Question 11); 29% ($n = 2$) wore spectacles. The ratio of contact lens to spectacle wearers for respondents requiring vision correction was 1:2

The difference between exposed and control subjects for use of vision correction during flight (35% versus 43%) was not statistically significant ($p = .698$).

Sighting eye preference

Sixty-one percent (*n* = 14) of control subjects reported their right eye as their preferred sighting eye; 26% (*n* = 6) reported their left eye as their preferred sighting eye (Question 17). Four percent (*n* = 1) of subjects reported equal preference, and 9% (*n* = 2) reported they did not know. For the specific viewing tasks of sighting with a telescope and viewing through a keyhole (Questions 18 and 19), 78% (*n* = 18) indicated right eye preference for telescope viewing, and 87% (*n* = 20) indicated right eye preference for viewing through a keyhole.

Eighty-six percent (*n* = 6) of exposed subjects reported their right eye as their preferred sighting eye; 14% (*n* = 1) reported their left eyes as their preferred sighting eye (Question 17). For the specific viewing tasks of sighting with a telescope and viewing through a keyhole (Questions 18 and 19), all seven (100%) indicated right eye preference for telescope and keyhole viewing.

When exposed subjects were asked if their "preferred eye was the same one (currently) as prior to AH Mk 1 training," 71% (*n* = 5) responded "Yes;" one subject did not respond.

There was no significant difference between the exposed and control subjects for sighting eye preference (*p* = .723).

<u>Visual problems</u>

Flight-related visual symptoms

When control subjects were asked to report on the presence ("Sometimes" or "Always") of visual/physiological problems *during* flight (Question 21), headache (63% of responding subjects; 52% of all subjects) and disorientation (56% of responding subjects; 44% of all subjects) were the most frequently cited symptoms; *after* flight (Question 22), headache was the most frequently reported symptom (48%).

Exposed subjects reported disorientation (71%), headache (57%) and visual discomfort (43%) as the most frequently cited *during* flight (Question 21) and afterimages (57%) and headache (43%) as the most frequent *after* flight (Question 22).

Headache was the most commonly reported symptom by both exposed and control subjects. For control subjects, headache was reported by nearly half of the subjects both *during* and *after* flight. For exposed subjects, afterimages was the most frequently reported symptom *after* flight, with headache rated second; disorientation was the most frequently reported symptom *during* flight. A two-way contingency table analysis was conducted to evaluate whether exposed subjects reported a different headache frequency than control subjects, either *during* or *after* flight. No statistically significant differences were found either *during* ($\chi^2 = 0.08$; $p = .780$) or *after* ($\chi^2 = 0.05$; $p = .818$) flight. Similar tests were conducted for disorientation ($\chi^2 = 0.53$; $p = .467$) and visual discomfort ($\chi^2 = 0.29$; $p = .592$) *during* flight; no statistically significant differences were present. However, when the frequencies of afterimages *after* flight were evaluated, a statistically significant difference was found ($\chi^2 = 5.83$; $p = .016$).

Tables 3 and 4 summarize the reported symptoms for both *during* and *after* flight, respectively.

Table 3.
Reported visual/physiological symptoms *during* flight.

	Control (n = 23) / Exposed (n = 7)			
	Never	Sometimes	Always	No response
Visual discomfort	57% / 57%	26% / 43%	0% / 0%	17% / 0%
Headache	30% / 43%	52% / 57%	0% / 0%	17% / 0%
Double vision	83% / 86%	0% / 14%	0% / 0%	17% / 0%
Blurred vision	78% / 71%	4% / 29%	0% / 0%	17% / 0%
Afterimages	74% / 71%	9% / 29%	0% / 0%	17% / 0%
Disorientation	35% / 29%	44% / 71%	0% / 0%	22% / 0%
Dizziness	83% / 100%	0% / 0%	0% / 0%	17% / 0%
Nausea	70% / 100%	13% / 0%	0% / 0%	17% / 0%

Table 4.
Reported visual/physiological symptoms *after* flight.

	Control (n = 23) / Exposed (n = 7)			
	Never	Sometimes	Always	No response
Visual discomfort	87% / 86%	13% / 14%	0% / 0%	0% / 0%
Headache	52% / 57%	48% / 43%	0% / 0%	0% / 0%
Double vision	100% / 86%	0% / 14%	0% / 0%	0% / 0%
Blurred vision	91% / 71%	7% / 29%	0% / 0%	0% / 0%
Afterimages	87% / 43%	13% / 57%	0% / 0%	0% / 0%
Disorientation	96% / 86%	4% / 14%	0% / 0%	0% / 0%
Dizziness	96% / 100%	4% / 0%	0% / 0%	0% / 0%
Nausea	87% / 100%	13% / 0%	0% / 0%	0% / 0%
Unsteadiness or balance problem	100% / 86%	0% / 14%	0% / 0%	0% / 0%

Eye fatigue

Viewing natural scenes is easy on the human visual system. However, prolonged viewing of displays, such as computer monitors, has resulted in reports of eye fatigue (McCown, 1999). Viewing imagery on HMDs is quite different from viewing the natural environment because an HMD is a display (Meltzer and Moffitt, 1997).

Viewing natural scenes with both eyes is an effortless and comfortable experience. This is because natural scenes have perfect alignment. Viewing imagery on binocular HMDs, e.g. NVGs, can result in the images seen by the two eyes having differences in magnification,

brightness, distortion and vertical, horizontal, or rotational alignment. As a result, the left- and right-eye images can be different in multiple ways (Melzer and Moffitt, 1997).

Of the 22 responding control subjects, 20 (91%) reported eye fatigue, to some extent, during night flight as a result of using NVGs (Question 25); one subject did not respond.

Five percent (n = 1) of responding control subjects reported experiencing symptoms of faintness, greying or loss of vision during periods of "aggressive" flying (Question 30). This subject reported actually being at the controls while experiencing these symptoms.

Eighty-six percent (n = 6) of exposed subjects reported eye fatigue, to some extent, during night flight as a result of using the IHADSS (Question 25). This percentage decreased to 50% (of those responding) for day use of the PNVS/IHADSS system; one subject did not respond.

The IHADSS system is dichoptic in nature, i.e., presenting two dissimilar images, one to each eye. The right eye views the HDU presentation, and the left eye views the outside world. This design can lead to a number of undesirable visual responses, including binocular rivalry and suppression (Klymenko and Rash, 1995). *During* flight, 57% (n = 4) of exposed subjects reported experiencing unintentional alternation of visual inputs to some degree (Question 27). Only one subject reported a continuation of alternation symptoms following flight and then only to a minor degree (Question 28).

A two-way contingency table analysis was conducted to evaluate whether exposed subjects (86%) presented a different proportion of eye fatigue than control subjects (91%). No significant difference was found (χ^2 = 0.16, p = .694).

<u>Color adaptation</u>

Of the 22 responding control subjects, 14 (64%) reported experiencing color perception problems after flying with NVGs. All of these subjects reported a persistent "browned vision" for up to 15 min post-flight (Question 29). This color anomaly has been well documented and has been called "brown eye syndrome" (Glick and Moser, 1974).

For exposed subjects, the IHADSS imagery is considered monochromatic (single color), presenting a green image at the predominate wavelength of 543 nanometers (nm). Prolonged viewing of such an image can result in color adaptation that can temporarily affect color vision immediately following viewing, as experienced with NVGs. Two exposed subjects (29%) reported this phenomenon, with one of these two subjects reporting the effects disappearing in less than 15 min post-flight and the other subject reporting the effects disappearing in 1 to 2 hr post-flight (Question 29).

The problem of color after-effects after using HMDs was raised in the early 1970s (Glick and Moser, 1974). This phenomenon was reported by U.S. Army aviators using NVGs for night flights. It was initially, and incorrectly, called "brown eye syndrome." The reported visual problem was that aviators experienced only brown and white color vision for a few minutes following NVG flight. Glick and Moser (1974) investigated this phenomenon and concluded

that the aviators' eyes were adapting to the monochromatic green output of the NVGs, i.e., cone saturation being responsible for this effect. The final conclusion was that this phenomenon was a normal physiological response and was not a concern (Rash, 2000).

A two-way contingency table analysis was conducted to evaluate whether exposed subjects (29%) had a different proportion of color episodes than control subjects (64%). No significant difference was found ($\chi^2 = 2.64$, $p = .104$). This finding might be expected since both NVG and IHADSS stimuli are provided by a monochromatic phosphor dominant in the green part of the visible spectrum.

Disorientation

Spatial disorientation (SD) is defined in the UK as "a failure to perceive correctly one's position, motion or attitude with respect to the earth's surface (horizontal reference) or the acceleration due to gravity (vertical reference)" (Durnford et al., 1995).

Of the 23 control subjects, six (26%) reported having experienced SD during flight with NVGs (Question 32). Most of these occurrences were associated with episodes of "white out" or degraded NVG imagery. White out is a special condition where clouds of disturbed snow can obscure vision. A similar condition known as "brown out" is associated with clouds of dust.

For exposed subjects, 57% ($n = 4$) reported having experienced SD while flying with the IHADSS (Question 31). Almost all subjects who reported SD experiences cited the "bag phase" of training as when the experience occurred. The bag phase refers to the period of flight training when the Apache student pilot is learning to use the IHADSS. Flights in this phase occur in daytime, with the student pilot's section of the aircraft (rear seat) fully enclosed (hence the use of the term "bag"), preventing any view of the outside world. When asked about SD episodes following the training period (Question 32), only 1 (14%) reported such episodes.

Previous studies indicate that while the IHADSS imagery is designed to be at optical infinity and of a 1:1 ratio with the outside world, pilots report problems with apparent size and distance of objects (targets) as viewed in the IHADSS imagery (Crowley, 1991; Hale and Piccione, 1990). While 57% $n = (4)$ of exposed subjects reported objects to be "about the right size and distance," 29% ($n = 2$) reported them as "smaller and farther away," and one subject (17%) reported them being "larger and closer than reality" (Question 33).

When asked to what extent problems of time lags associated with changes in symbology values and actual aircraft movements existed during flight with the IHADSS (Question 34), only one exposed subject (14%) indicated a problem, "to a moderate extent." Regarding possible similar time lags between head movement and the PNVS image (Question 35), 43% ($n = 3$) of respondents reported "slight" problems. Several subjects commented about the slow slew rate of both the PNVS and, especially, the TADS sensors.

Due to the dichoptic viewing design of the IHADSS, pilots must switch attention back and forth between the IHADSS imagery on the HDU (in the right eye) and the view of the outside world (in the left eye). When asked how frequently this switching is needed during flight

(Question 36), only one exposed subject (14%) reported "Always," and 57% (n = 4) reported "50% of the time" or more. Three subjects (43%) reported having experienced a "wash out" of right eye HDU imagery as a result of a flash of light into the left, unaided eye (Question 37).

While flight imagery is presented egocentrically in front of the right eye, the imagery actually originates from the PNVS mounted forward-looking infrared (FLIR) sensor located approximately 10 feet (ft) forward and 3 ft below the pilot's design eye position. Brickner (1989) and Rash (2000) suggest that this exocentric positioning of the imagery source can produce problems of apparent motion, parallax, and incorrect distance estimation, among other perceptual problems (). Of exposed subjects, 57% (n = 4) reported that this exocentric viewing condition created problems with obstacle clearance, mostly during taxiing and ground hover (Question 38).

In anticipation of possible visual fatigue effects of long flights (over two hours) on viewing of symbology, subjects were asked if the symbology ever "disappeared" during such flight (Question 39). Only 29% (n = 2) of exposed subjects reported such incidents, but both subjects reported this situation as happening less than "50% of the time."

A two-way contingency table analysis was conducted to evaluate whether exposed subjects have a different proportion (57%) of SD episodes than control subjects (26%). The greater proportion for exposed subjects was not found to be significant (χ^2 = 2.33, p = .127). Following the completion of the "bag" phase of training, the percentage of exposed subjects reporting SD episodes decreased to 14%. A two-way contingency table analysis found no statistical difference between the two proportions (χ^2 = 2.80, p = .094).

Handedness inventory

Subject handedness was assessed using a ten-item self-reporting questionnaire adapted from the Edinburgh Handedness Inventory (EHI) by Oldfield (1971). All exposed and control subjects completed the EHI questionnaire at some point in the study. Subjects were asked to indicate their preference in use of hands for various activities, e.g., writing, throwing, using a toothbrush, etc. Both absolute and relative scores were computed for each subject. The absolute score was based on the majority of the 10 responses in deciding between "right-" and "left-" handedness for the various activities. The EHI relative score was a number between –100 and +100, as calculated by the expression [(#R - #L)/(#R + #L)] X 100, where #L and #R were the total number of left and right hand responses, respectively. A negative score indicates a tendency toward left-handedness; a positive score indicates a tendency toward right-handedness.

The absolute handedness scores were predominately "right" with 87% (n = 20) of control subjects indicating a preference for right-handedness and 13% (n = 3) indicating left-handedness. The EHI relative scores confirmed this finding with the same distribution: 87% (n = 20) indicating right-handedness and 13% (n = 3) indicating left-handedness (Figure 3). The median EHI relative score was for control subjects was +78, with 30% (n = 7) of respondents indicating an overwhelming preference (+100) for right-handedness. The mean EHI relative handedness score was +63.

The IHADSS system is monocular in design, providing imagery to the right eye only. It has been suspected that pilots who are left-eye dominant may have increased difficulty learning and using the right-eyed IHADSS (Rash, 2000). While eye dominance only weakly correlates with handedness (Coren, 1993), it was deemed potentially useful to measure handedness; therefore, this property was measured during the physical eye exam.

The absolute handedness scores were predominately "right" with six (86%) exposed subjects indicating a preference for right-handedness and one (14%) indicating left-handedness. The EHI relative scores confirmed this finding with the same distribution: 86% indicating right-handedness and 14% indicating left-handedness (Figure 4). For exposed subjects, the median EHI relative score was +100, with four subjects (57%) indicating an overwhelming preference (+100) for right-handedness. The mean relative handedness score was +66.

Both exposed and control subject groups indicated a predominate preference for right-handedness. A chi-square test showed no significant difference between the proportions of exposed subjects (86%) and control subjects (87%) (p = .933).

The difference between the mean relative EHI scores of the two groups was not statistically significant (p = .922). The exposed group had a larger proportion (57% to 30% for the control group) of overwhelming right-handedness relative scores (+100), but there was no statistically significant difference between the two groups (p = .119).

The one exposed subject who indicated left eye preference had both absolute and relative (+54) right-handedness scores. Of the control group, 26% (n = 6) indicated left-eye preference. Twenty-two percent (n = 5) had right-handedness absolute and relative scores, and 4% (n = 1) had left-handedness absolute and relative (-50) scores.

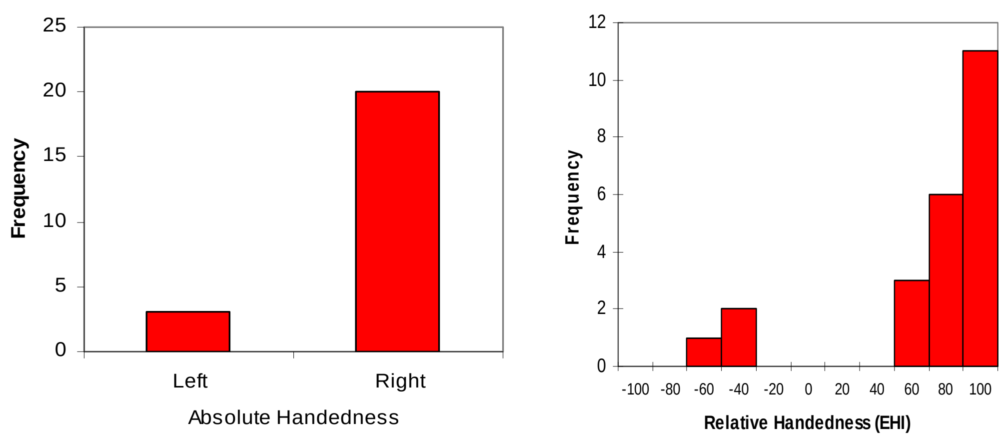

Figure 3. Absolute and relative handedness for control subjects.

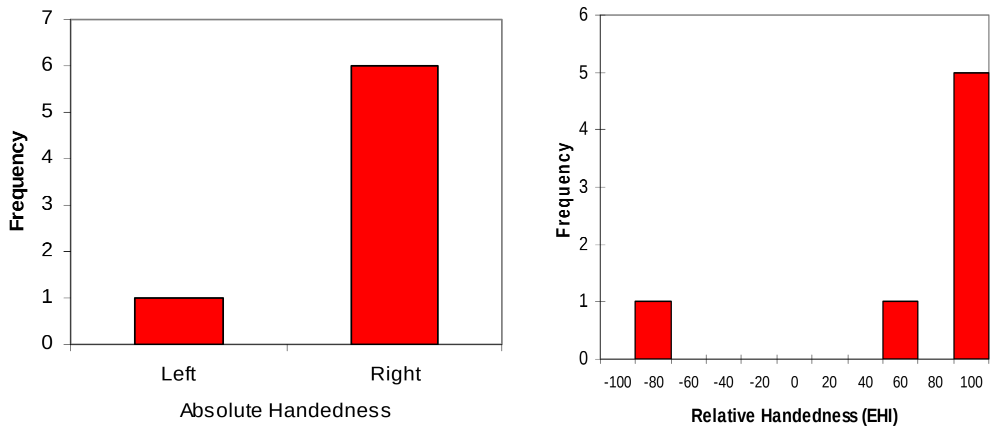

Figure 4. Absolute and relative handedness for exposed subjects.

In the general population, the proportion of right-handed people ranges from 90 to 95% (Augustyn and Peters, 1986; Brown and Taylor, 1988), therefore the proportions cited here for the exposed and control groups are similar to those reported in the general population.

Special exposed subject issue- IHADSS imagery

When using the IHADSS, flight imagery and symbology are presented on the HDU. Flight imagery is the picture of the outside world as produced by the nose FLIR sensor. Symbology is a set of alphanumeric and pictograms used to present flight information such as altitude, airspeed and heading. Optically, the HDU imagery is at optical infinity. No responding exposed subjects indicated having difficulty in seeing or interpreting the IHADSS symbology (Question 23); one subject did not respond. Almost three-fourths (71%) of subjects reported having at least a minimal problem focusing on both the outside world and the HDU symbology simultaneously (Question 24); one subject (14%) reported experiencing such difficulty over "50% of the time."

Eye examination

A series of nine visual tests were administered as an adjunct eye examination component of the regular annual flight physical. Tests of visual performance were conducted monocularly and/or binocularly except where inapplicable (e.g., in eye dominance testing). Visual acuity and contrast sensitivity were measured with the subject's habitual vision correction (spectacles or contact lenses) if the subject presented with correction at the time of the examination. Full eye examination data are presented in Appendices A (Control) and B (Exposed).

Refractive error

Each subject's refractive error was measured monocularly using an autorefractor (Model AR-600, Nidek Co., LTD., Tokyo, Japan). A single reading was taken for each eye. Each recorded measurement consisted of a sphere, cylinder and axis value. Due to logistical and travel issues associated with remote subject locations, autorefractor data were not available for all subjects.

Nineteen control subjects were measured during the last examination cycle. The ranges for spherical and cylindrical refractive errors (across both eyes) were -1.50 to +2.25 dioptres and -1.50 to -0.25 dioptres, respectively. The means for spherical refractive error were +0.30 (*SD* = 0.66), +0.32 (*SD* = 0.74) and +0.31 (*SD* = 0.61) dioptres for right eye, left eye, and both eyes, respectively. The means for cylindrical refractive error were -0.59 (*SD* = 0.42), -0.49 (*SD* = 0.27) and -0.54 (*SD* = 0.29) dioptres for right eye, left eye and both eyes, respectively.

Five exposed subjects were measured; autorefractor data were not available for two subjects. The ranges for spherical and cylindrical refractive error (across both eyes) were -2.75 to +0.25 dioptres and -1.00 to -0.25 dioptres, respectively. The means for spherical refractive error were -0.50 (*SD* = 1.27), -0.45 (*SD* = 1.05), and -0.48 (*SD* = 1.16) dioptres for right eye, left eye and both eyes, respectively. The means for cylindrical refractive error were -0.50 (*SD* = 0.31), -0.45 (*SD* = 0.27), and -0.48 (*SD* = 0.24) dioptres for right eye, left eye and both eyes, respectively.

The spherical equivalent power is a standard method for summarizing refractive error into one number and is determined by combining the spherical power with half of the cylindrical power. The means for spherical equivalent (average power) for control subjects were +0.01 (*SD* = 0.64), +0.07 (*SD* = 0.70) and +0.04 (*SD* = 0.58) dioptres for right, left and both eyes, respectively. The means for spherical equivalent (average power) for exposed subjects were -0.75 (*SD* = 1.41), -0.68 (*SD* = 1.12) and -0.71 (*SD* = 1.26) dioptres for right, left and both eyes, respectively. Box plots of the spherical equivalent refractive error for the right and left eyes for both exposed and control subjects are presented in Figure 5.

Aviators tend to have a low level of refractive error as a result of limits set during selection for aviation. In the UK, for aviators entering flight school, vision unaided in each eye must not be less than 6/12 (20/40), and each eye correctable to 6/6 (20/20). The strength of the required correction cannot exceed -0.75 to +1.75 dioptres (spherical) and the astigmatic element must not be greater than +/-0.75 dioptres (cylindrical). There is a tendency for refractive error to increase with age, especially in the mid to late twenties, and for individuals to develop presbyopia in their early forties. Both of these factors lead to an increased prevalence of spectacle wear with age, where individuals who did not previously need spectacles develop the need for refractive correction.

The mean spherical equivalent refractive error for controls was essentially zero, equivalent to emmetropia, while the exposed group had a mean spherical equivalent refractive error in the myopia range: -0.75 for the right eyes and -0.68 for left eyes. These differences were not statistically significant (right eyes, $p = .085$; left eyes, $p = .075$). These numerical differences are most likely due to the difference in age of the two groups, in keeping with there being a trend toward increasing myopia with age (There was a four-year difference between group mean ages.).

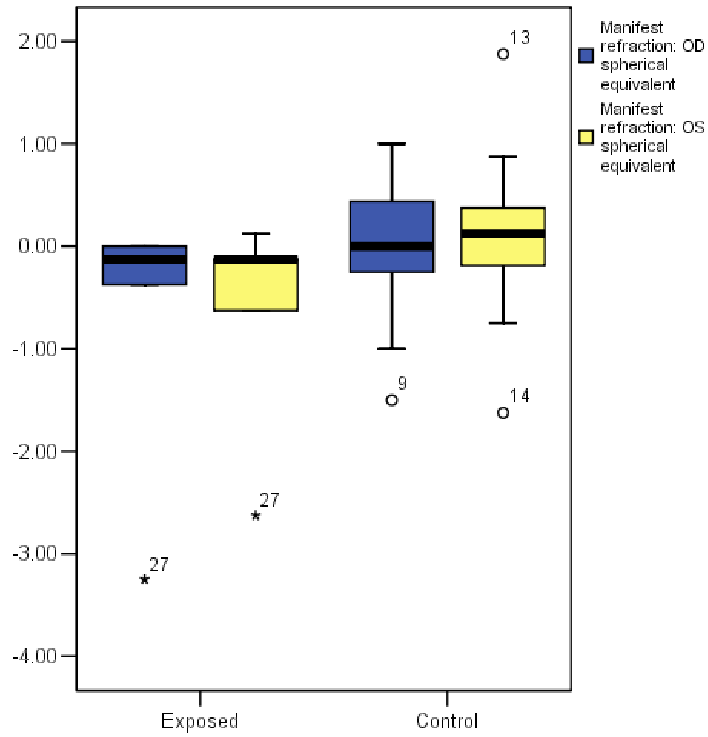

Figure 5. Box plot of spherical equivalent refractive error for the right (OD) and left (OS) eyes for exposed and control subjects.[3]

Bailey-Lovie high contrast visual acuity (HCVA)

This test is designed to measure static visual acuity in a high contrast lighting environment. A chart luminance of approximately 100 candelas per square meter (cd/m^2) was used. Unlike most visual acuity chart, the lines are arranged five letters per line, and the spacing is proportional to ensure equal visual demand near threshold. The Bailey-Lovie charts (Figure 6) allow the expression of acuity as the logarithm of the minimum resolvable angle (logMAR) and since each letter is scored, the scoring of acuity is a more continuous variable than the conventional Snellen charts (Bailey and Lovie, 1976). This test was conducted monocularly for both left and right eyes using the habitual correction (either prescribed glasses or no glasses). The test was scored as the total number of letters missed (incorrectly or unidentified letters).

[3] The bold bar represents the median value. Values that fall between 1.5 and 3 box-lengths are called *outliers* and are designated using the “o” symbol; values that fall beyond 3 box-lengths are called *extremes* and are designated by the “*” symbol. The box-length is equivalent to the interquartile range of the data set.

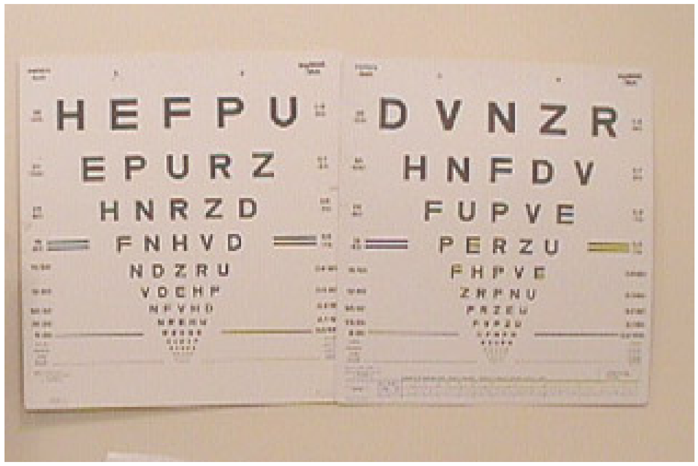

Figure 6. Bailey-Lovie acuity charts.

For clinical interpretation, the mean scores were converted into logMAR using the formula logMAR = -0.3 + N(0.02) where N is the number of letters missed. Conversion from logMAR to Snellen acuity (20/xx) is accomplished using the formula to determine the Snellen denominator: $xx = 20 \times 10^{\text{logMAR}}$.

For the last measurement cycle, values were available for all 23 control subjects. For the right eye, the mean visual acuity was 0.08 logMAR (Snellen equivalent of 6/7.5 [20/24]) with a standard deviation of 0.10 logMAR. For the left eye, the mean visual acuity was 0.09 logMAR (Snellen equivalent of 6/7.5 [20/24]) with a standard deviation of 0.10 logMAR.

For the seven exposed subjects, for the right eye, the mean visual acuity was 0.13 logMAR (Snellen equivalent of 6/8 [20/27]) with a standard deviation of 0.06 logMAR. For the left eye, the mean visual acuity was 0.13 logMAR (Snellen equivalent of 6/8 [20/27]) with a standard deviation of 0.10 logMAR.

The mean visual acuities in logMAR, based on the Bailey-Lovie high contrast chart, for the right and left eyes of control and exposed subjects are presented in Figure 7.

Visual acuity is an important measure of visual capability of pilots. While visual acuity was expected to be 6/6 (20/20) or better (0.00 logMAR) for this population, the actual measures were closer to 6/7.5 (20/24 or 0.08 logMAR) for the control subjects and 6/8 (20/27 or 0.12 logMAR) for exposed subjects. This reduced acuity was a consequence of measurements using each pilot's own eyeglasses, which may or may not be current, or for those subjects reporting for testing without glasses or low amounts of uncorrected refractive error. There was not a statistically significant difference in the high contrast visual acuity of the two groups (right eyes, $p = .06$; left eyes, $p = .23$).

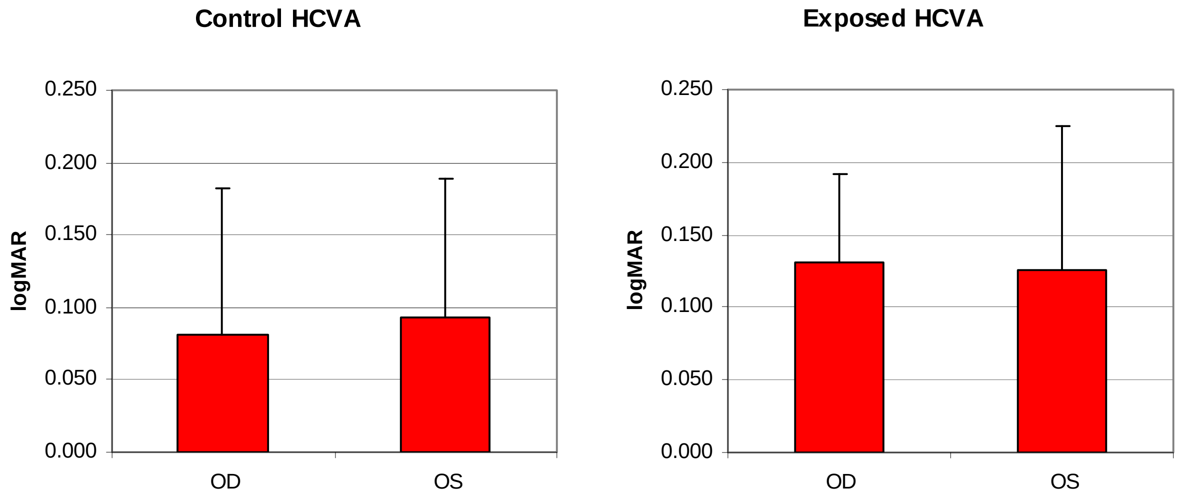

Figure 7. Mean Bailey-Lovie high contrast logMAR acuity for right (OD) and left (OS) eyes for control (left) and exposed (right) subjects.

Bailey-Lovie low contrast visual acuity (LCVA)

This test was designed to measure static visual acuity in a low contrast environment, more representative of the real-world aviation environment. The letters on the low contrast side of the chart are 10% (Michelson) contrast. All criteria of the high contrast-test above were applied to this test. This test was conducted monocularly for both right and left eyes. Due to availability of the Bailey-Lovie LCVA chart at the various test locations, these data may be missing for some subjects.

For the last measurement cycle, values were taken for 13 control subjects. For the right eye, the mean low contrast acuity was 0.45 logMAR (Snellen equivalent of 6/17 [20/56]) with a standard deviation of 0.31 logMAR. For the left eye, the mean low contrast acuity was 0.41 logMAR (Snellen equivalent of 6/15 [20/51]) with a standard deviation of 0.22 logMAR.

Values for seven exposed subjects were taken in the last measurement cycle. For the right eye, the mean low contrast acuity was 0.43 logMAR (Snellen equivalent of 6/16 [20/54]) with a standard deviation of 0.07 logMAR. For the left eye, the mean low contrast acuity also was 0.43 logMAR (Snellen equivalent of 6/16 [20/54]) with a standard deviation of 0.08 logMAR.

The ability to see low contrast letters is affected by the optics of the eye, uncorrected refractive error, and/or the sensitivity of the retina. Optics of the eye include clarity of the media, specifically the cornea and lens, and pupil size; both tend to decrease with age. The mean age difference between the two groups was very small at 3 years, the two groups are still relatively young, and changes are generally not evident until the fifth or sixth decade of life. There was not a statistically significant difference in the low contrast visual acuity of the two groups for either right or left eyes (right eyes, $p = .42$; left eyes, $p = .36$).

The mean 10% low contrast visual acuities in terms of logMAR for the right and left eyes of control and exposed subjects are presented in Figure 8.

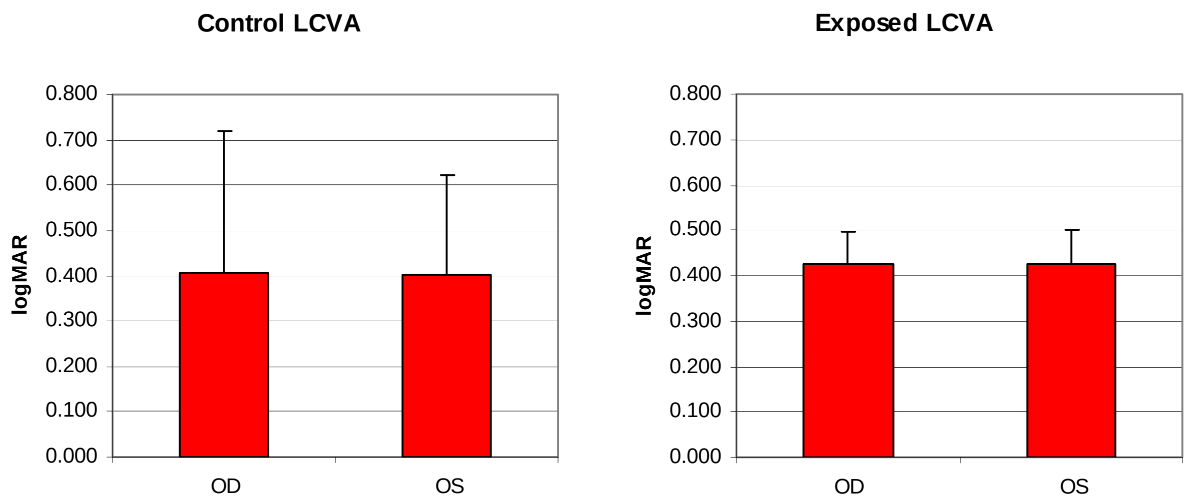

Figure 8. Mean Bailey-Lovie low contrast logMAR acuity for right (OD) and left (OS) eyes for control (left) and exposed (right) subjects.

<u>Small letter contrast sensitivity</u>

This test (small letter contrast test [SLCT]) used a chart developed at USAARL (Figure 9) that presents rows of letters of one size decreasing in contrast level by 0.1 log for each row on the chart. It is a measure of small letter contrast sensitivity (CS) and has been shown to be sensitive to slight changes in visual performance (Rabin and Wicks, 1996). The subject was asked to read down the chart's left side, giving the first letter of each row. When the subject appeared to hesitate at a specific row, that row was used as the threshold for beginning the test. The subject was asked to begin reading the preceding entire row of letters, continuing as far down the chart as possible. This test was conducted monocularly for both left and right eyes using habitual correction. The measured data value is the total number of incorrect (unreadable) letters. Each score is converted into a meaningful value of logCS using the formula logCS = 1.3 – N(0.01), where N is the total number of missed letters. The mean expected score on this test is logCS = 1.1. Scores below 0.8 are considered below normal (Rabin, 2003; van de Pol, 2003).

For the last measurement cycle, values were taken for 21 control subjects. For the right eye, the mean contrast sensitivity was 1.01 logCS (*SD* = 0.21; range = 0.48 to 1.30 logCS). For the left eye, the mean was 0.99 logCS (*SD* = 0.23; range = 0.47 to 1.29 logCS).

Figure 9. Test chart for small letter contrast sensitivity.

Values for all seven exposed subjects were taken in the last measurement cycle. For the right eye, the mean contrast sensitivity was 0.92 logCS (*SD* = 0.19; range = 0.68 to 1.18 logCS). For the left eye, the mean was 0.93 logCS (*SD* = 0.23; range = 0.57 to 1.16 logCS).

The mean small letter contrast sensitivity for control and exposed subjects is shown in Figure 10.

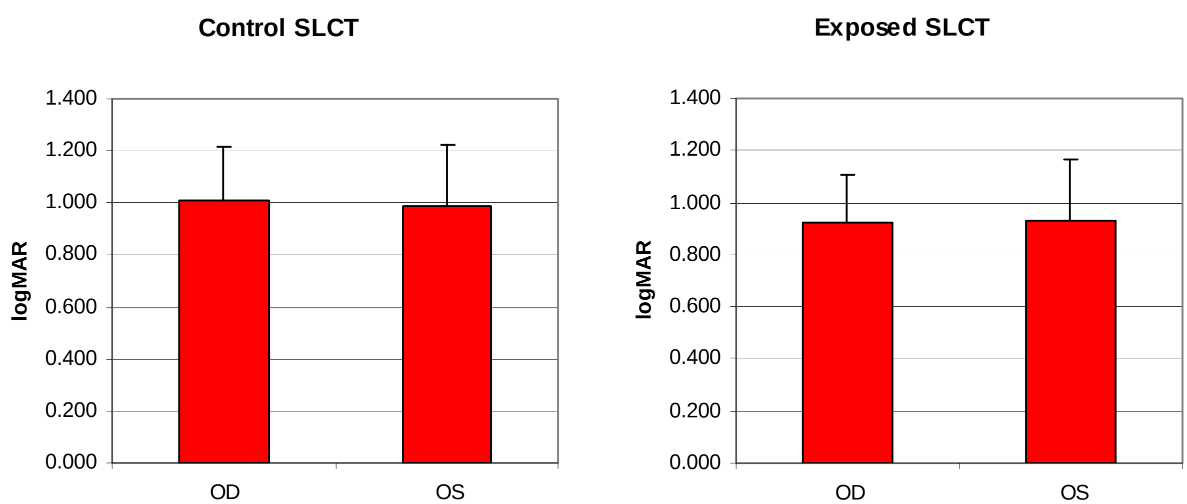

Figure 10. LogCS scores for the right and left eyes for control (left) and exposed (right) subjects.

Retinal sensitivity, a factor in the ability to see low contrast letters, also declines with age; however, the same general trends apply as seen with optical changes with age. Fewer subjects in

each group were measured on this test than for the high contrast visual acuity test, as previously explained. There was not a statistically significant difference between groups for the SLCT results (right eyes, $p = .15$; left eyes, $p = .28$).

Depth perception

Depth perception (stereopsis) was measured using the Stereotest-Circles test (Stereo Optical Co., Inc., Chicago, Illinois) (Figure 11). Wearing polarized glasses, subjects viewed arrangements of three circles and determined which circle in each group of three appeared closest. The recorded data point was the angular measure of the last correct answer, expressed in seconds of arc. The test was performed binocularly.

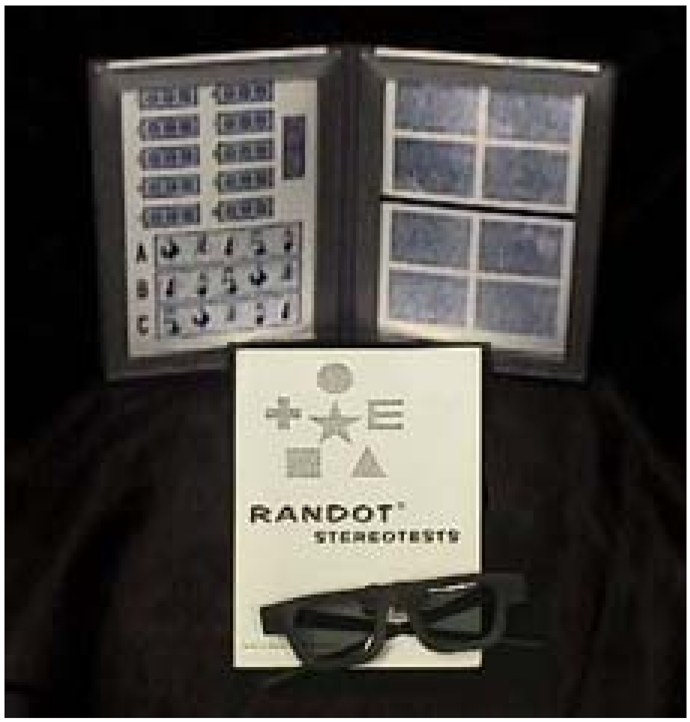

Figure 11. The Stereotest-Circles depth perception test.

Depth perception values for control subjects ranged from 20 to 50″ with a median of 25″ (*SD* = 5.73). Exposed subjects had depth perception values ranging from 20 to 30″ with a median of 25″ (*SD* = 3.45). The distribution of depth perception values is presented in Figure 12.

The mean depth perception scores for the control and exposed groups represent excellent depth perception; 40 seconds of arc or better is the standard for U.S. Army aviators. Only one control subject performed worse than this standard. There was not a statistically significant difference between the groups ($p = .728$).

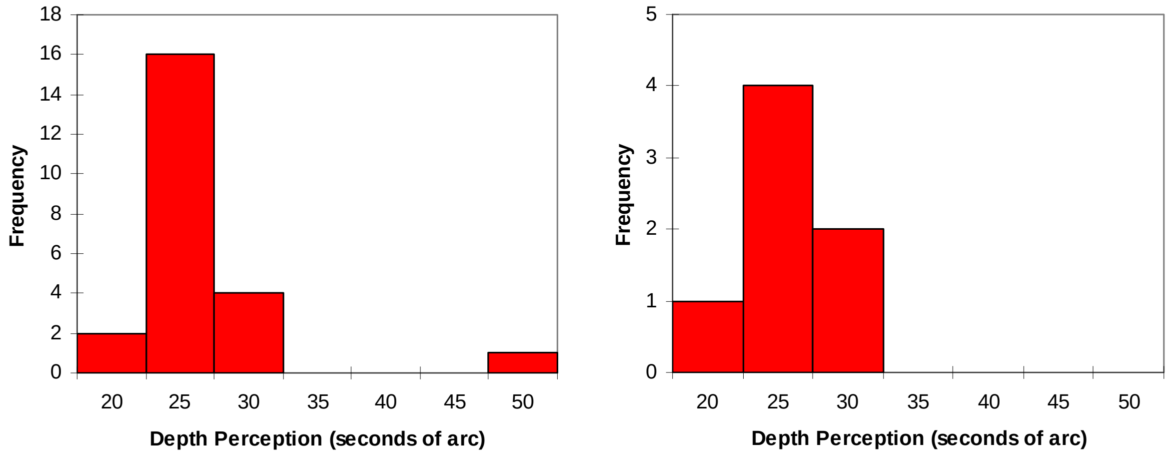

Figure 12. Frequency distribution for depth perception values for control (left) and exposed (right) subjects.

Color perception

The L'Anthony desaturated D-15 hue test (Figure 13), adapted from the Farnsworth panel D-15 test was used. This test consists of 16 color chips/tabs selected from the Munsell book of color that are desaturated and appear pale and light. The subject's task is to arrange the color chips in order according to color starting with the base/fixed cap. In order to compare small differences in performance, a modified Farnsworth FM-100 test quantitative perception scoring scheme was used. When all caps are correct, the color perception score is 56.3. Errors in the cap sequencing result in an increase in score. The mean expected score is 64 with a range of normal scores falling between 56.3 (perfect sequence) and 80 (Geller, 2001). This test was conducted monocularly for both left and right eyes. Scoring was performed using VisionScience Software's (Elk City, Oklahoma) Color Vision Analyzer, a software program designed for analyzing the L'Anthony desaturated D-15 hue test.

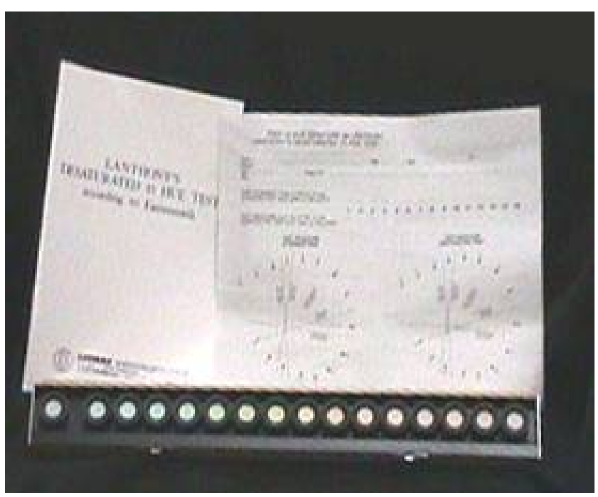

Figure 13. The L'Anthony desaturated D-15 hue test.

For control subjects, the mean color score for the right eye was 65.1 (*SD* = 20.64; range 56.3 to 156.6); the median score was 60.4. For the left eye, the mean color score was 65.9 (*SD* = 23.92; range 56.3 to 167.3); the median score was 56.3. Three subjects scored outside the normal range of 56.3 to 80.

For exposed subjects, the mean color score for the right eye was 63.4 (*SD* = 11.42; range 56.3 to 81.0); the median score was 56.3. For the left eye, the mean color score was 64.8 (*SD* = 16.66; range 56.3 to 101.5); the median score was 56.3. Two subjects scored outside the normal range in one of their eyes.

Color perception scores are presented in Figure 14.

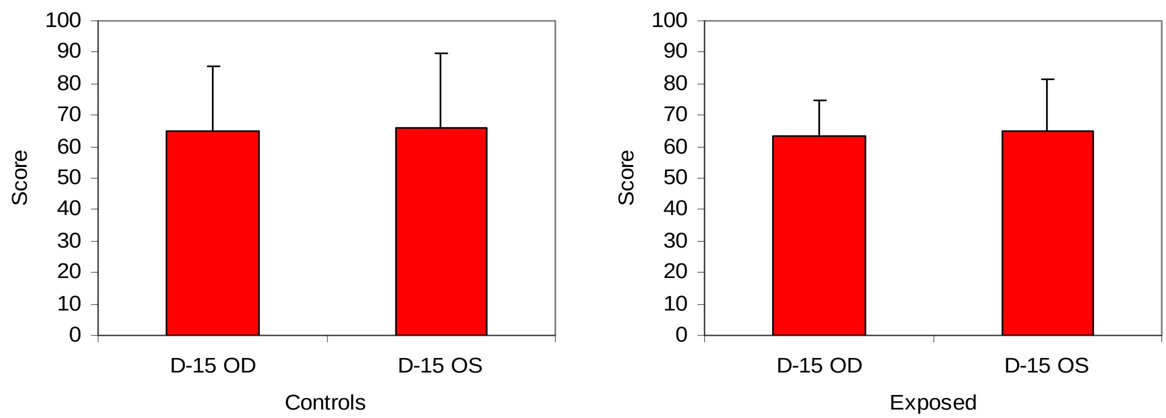

Figure 14. Mean color perception scores for right (OD) and left (OS) eyes of control (left) and exposed (right) subjects.

On average, exposed subjects had only a slightly lower (better) color perception score than control subjects. The three control subjects who were outside the norms for color perception may have mild to moderate levels of color deficiency. Among the exposed subjects, two were outside the norms for color perception and also may have mild levels of color deficiency. There was not a statistically significant difference between the groups (right eyes, $p = .842$; left eyes, $p = .911$).

Accommodation

In a standard aircrew medical examination, accommodation is measured in a binocular fashion, stimulating convergence and accommodation together by maintaining focus and fusion on a target. In this study, accommodation without spectacle correction was tested binocularly and monocularly by moving a small-print target on a Prince Rule (Figure 15) slowly away from each eye in turn, noting when the subject can read the letters on the target. The values recorded were the measured distances, expressed in centimeters (cm). These values were converted into dioptre values (the inverse of the focusing distance in meters [m]). In order to determine true accommodative capability, the results obtained without spectacle correction were adjusted by the spherical equivalent refractive error.

Figure 15. Accommodation rule test.

Twenty-three control subjects performed this test. The results are presented based on age (in decade increments); 5 subjects were 20 to 29 years of age (*M* = 27 years); 11 subjects were 30 to 39 years of age (*M* = 36 years); and 5 subjects were 40 to 49 years of age (*M* = 44 years). Two subjects were over 49 years of age and were not included in this analysis. Mean binocular accommodation was 6.7 dioptres (*SD* = 0.7) for the youngest group, 6.4 dioptres (*SD* = 1.8) for the 30 to 39 year group, and 4.1 dioptres (*SD* = 1.6) for the oldest group. Monocularly, the mean accommodation for the 20 to 29 year group was 6.5 dioptres (*SD* = 1.1) for the right eye and 6.6 dioptres (*SD* = 0.7) for the left eye. Monocularly, the mean accommodation for the 30 to 39 year group was 6.3 dioptres (*SD* = 2.3) for the right eye and 6.0 (*SD* = 1.5) for the left eye. Monocularly, the mean accommodation for the 40 to 49 year group was 3.8 dioptres (*SD* = 1.8) for the right eye and 4.1 dioptres (SD = 1.7) for the left eye. Accommodation values (in dioptres) by age group are presented in Figure 16.

All seven exposed subjects performed this test. The results are presented based on age; there were no subjects 20 to 29 years of age, 4 subjects were 30 to 39 years of age (*M* = 37), and three subjects were 40 to 49 years of age (*M* = 44). Mean binocular accommodation was 5.9 dioptres (*SD* = 0.9) for the younger group and 3.5 dioptres (*SD* = 1.3) for the older group. Monocularly, the mean accommodation for the 30 to 39 year old group was 5.5 dioptres (*SD* = 0.6) for the right eye and 5.7 dioptres (*SD* = 1.1) for the left eye. For the older group, the mean monocular accommodation was 3.3 dioptres (*SD* = 1.4) for the right eye and 3.4 dioptres (*SD* = 1.3) for the left eye. Accommodation values (in dioptres) by age group are presented in Figure 17.

The results of the accommodation test were broken down according to age, since accommodative capability naturally decreases with age (Borish, 1954). The control group included younger subjects between the ages of 20 and 29 years; there were no subjects in this age range for the exposed group. There was not a statistically significant difference between groups for the 30 to 39 year olds (right eyes, $p = .53$; left eyes, $p = .72$) or for the 40 to 49 year olds (right eyes, $p = .70$; left eyes, $p = .57$).

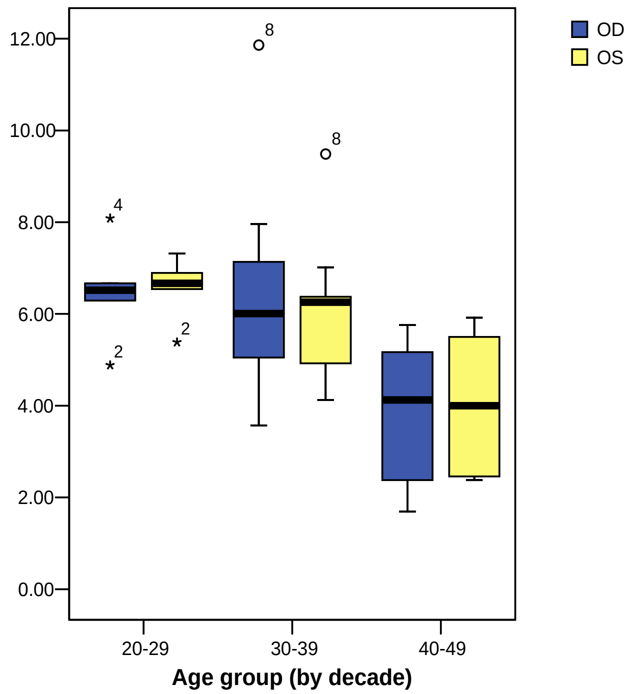

Figure 16. Accommodation by age group (decade) for control subjects.[4]

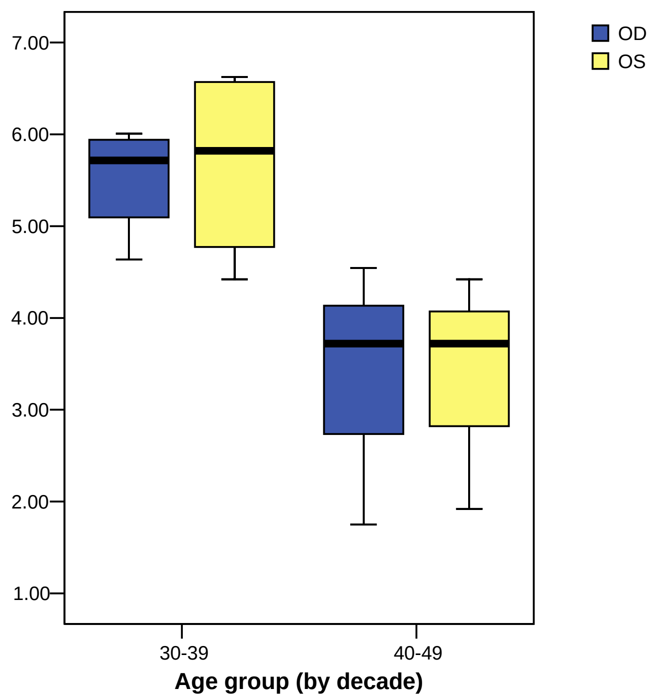

Figure 17. Accommodation by age group (decade) for exposed subjects.[2]

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[4] Values that fall between 1.5 and 3 box-lengths are called *outliers* and are designated using the “o” symbol; values that fall beyond 3 box-lengths are called *extremes* and are designated by the “*” symbol. The box-length is equivalent to the interquartile range of the data set.

Eye muscle balance

The eyes are held in place by three pairs of muscles that constantly balance the pull of the others. These muscles work together to move the eyes in unison, which allow the eyes to track moving objects. Binocular vision is a consequence of the separation of the eyes, which results in two views of the scene. To prevent double vision (diplopia), the eye uses a movement called "vergence." The eyes turn to direct the images directly onto the retina. The brain fuses these two images into one.

When both eyes fail to point to the same location in space, a condition known as heterotropia or strabismus exist. The condition is diagnosed using the unilateral cover test; the subject fixates on a point in space and one eye is covered. If the uncovered eye refixates to the point, this indicates the eye was not aligned. In cases of strabismus, individuals will see double or suppress the image of one eye; in either adaptation stereopsis will not exist. Both eyes are checked using the unilateral cover test. If neither eye refixates when the opposite eye is covered, strabismus is not present and the subject is considered orthotropic.

Covering one of the eyes and noting the change in the line of sight of the covered eye can test eye muscle balance. If both eyes accurately point toward the target when each eye is covered separately, this normal muscle condition is called orthophoria (Figure 18). If the line of sight departs from the target object, a condition known as heterophoria exists. Such departure can be either lateral or vertical in nature. If the line of sight of the covered eye laterally departs such as to turn outward, a condition called exophoria is present; if the line of sight of the covered eye laterally departs such as to turn inward a condition called esophoria is present (Figure 18). If the line of sight of either covered eye vertically departs from normal vergence, such that one line of sight is directed above the plane of the other, a condition called hyperphoria is present (Figure 19) (Borish, 1949).

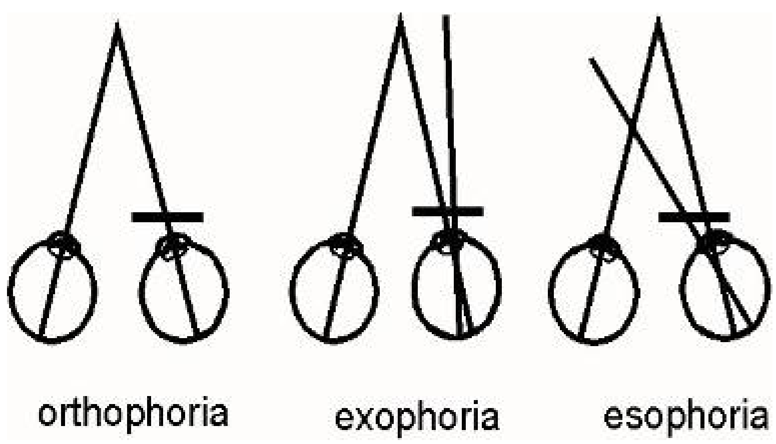

Figure 18. Diagram of orthophoria and lateral heterophorias (adapted from http://spectacle.berkeley.edu/cleere/glossaryNZ.html).

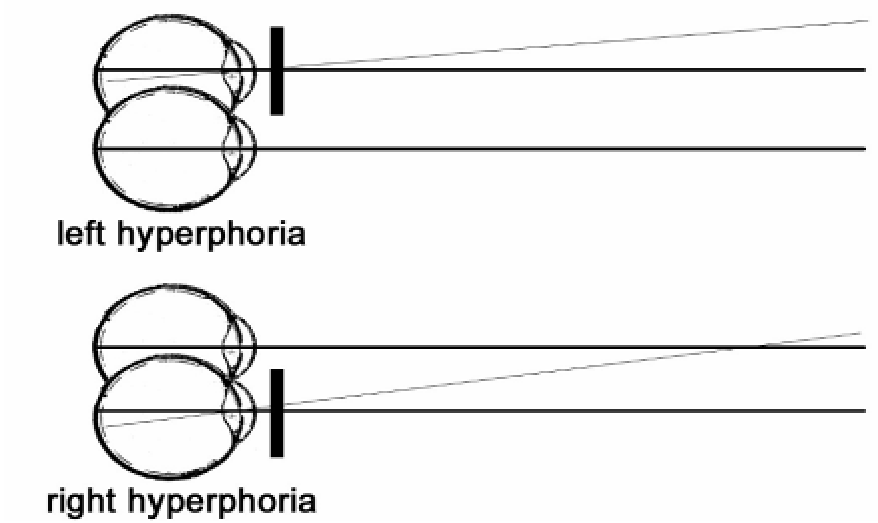

Figure 19. Diagram of hyperphoria.

In the two-year review report (Rash et al., 2004), a recommendation was made to replace the then-used Maddox rod test to measure muscle balance with some form of automated testing. This recommendation was based on the complexity and difficulty associated in the administration of this test by non-optometric medical personnel. As a result, in 2002, the Maddox rod device was replaced with the Optec® 2000 Vision Tester (Figure 20).

Figure 20. Eye muscle balance test equipment.

Eye muscle balance was measured for both a <u>distance</u> (6 m [20 ft]) and <u>near</u> (~½ m [18 in]) condition. If orthophoria was determined, it was so noted. If heterophoria was present the extent of the esophoria, exophoria or hyperphoria was recorded in prism dioptres. If hyperphoria was present, the eye in which it was found was recorded.

Twenty control subjects were measured. All subjects had a measurable heterophoria at <u>distance</u>; 17 (85%) were esophoric, three (15%) were exophoric and 10 (50%) were also

hyperphoric. Esophoria ranged from 1 to 8 prism dioptres; exophoria ranged from 1 to 2 prism dioptres; and hyperphoria ranged from 0.25 to 1 prism dioptre. All subjects had a measurable heterophoria at near; 16 (80%) were esophoric, three (15%) were exophoric and 13 (65%) were also hyperphoric; one subject (5%) only had hyperphoria. Esophoria ranged from 1 to 11 mean prism dioptres; exophoria ranged from 1 to 2 mean prism dioptres; and hyperphoria ranged from 0.5 to 1.5 mean prism dioptres (Figure 21).

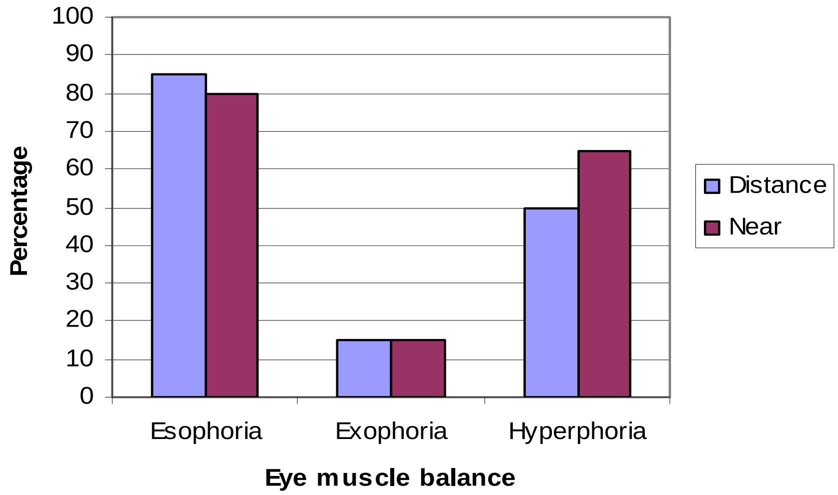

Figure 21. Eye muscle balance data for control subjects.

Eye muscle balance was measured for all seven exposed subjects. All subjects had a measurable heterophoria at distance; all (100%) were esophoric and five (71%) were also hyperphoric. Esophoria ranged from 2 to 7 prism dioptres and hyperphoria was 0.5 prism dioptres. All subjects (100%) were esophoric at near and six (85%) were also hyperphoric. Esophoria ranged from 1 to 8 mean prism dioptres and hyperphoria ranged from 0.5 to 1.5 mean prism dioptres (Figure 22).

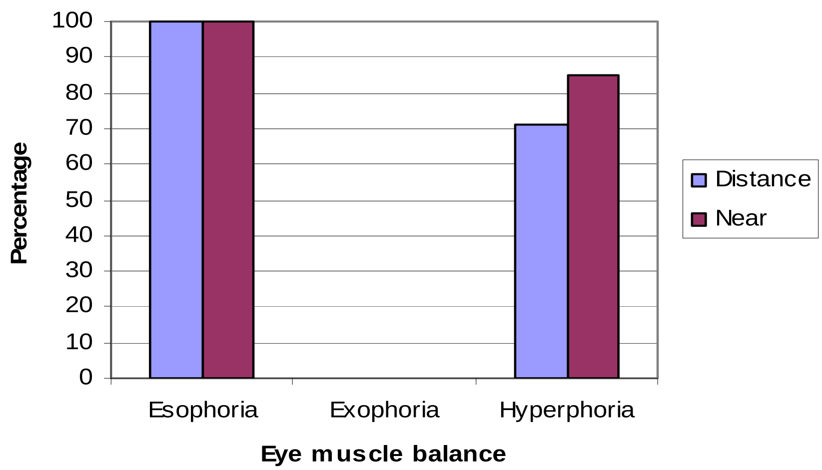

Figure 22. Eye muscle balance for exposed subjects.

Heterophoria is a measure of the solidness of ocular alignment and binocular fusion to a target at a given distance. For both groups, esophoria was the most common condition for both distant and near targets. The movement toward esophoria demonstrated by both groups as compared to the two-year report was very likely a result of the replacement of equipment for this test. Only three control subjects had exophoria, a divergence tendency, for distant or near viewing. The distribution of heterophorias was very similar for both groups and was not statistically different between groups (distance, p = .28; near, p = .21).

Eye preference

As a measure of eye preference a sighting dominance test was used. The selected test is called the "hole" test, in which the subject views the examiner's head through a hole in a card, then closes each eye alternately allowing the examiner to determine which eye was being used by the subject for sighting. The test was conducted under normal room lighting with the subject and examiner approximately 3 m (10 ft) apart. The test was repeated four times, and the predominant eye was recorded.

Sixty-five percent of control subjects were measured to have "right" eye preference. Fifty-seven percent of exposed subjects were measured to have "left" eye preference. The distribution of results for the eye preference test for control and exposed subjects is presented in Figure 23.

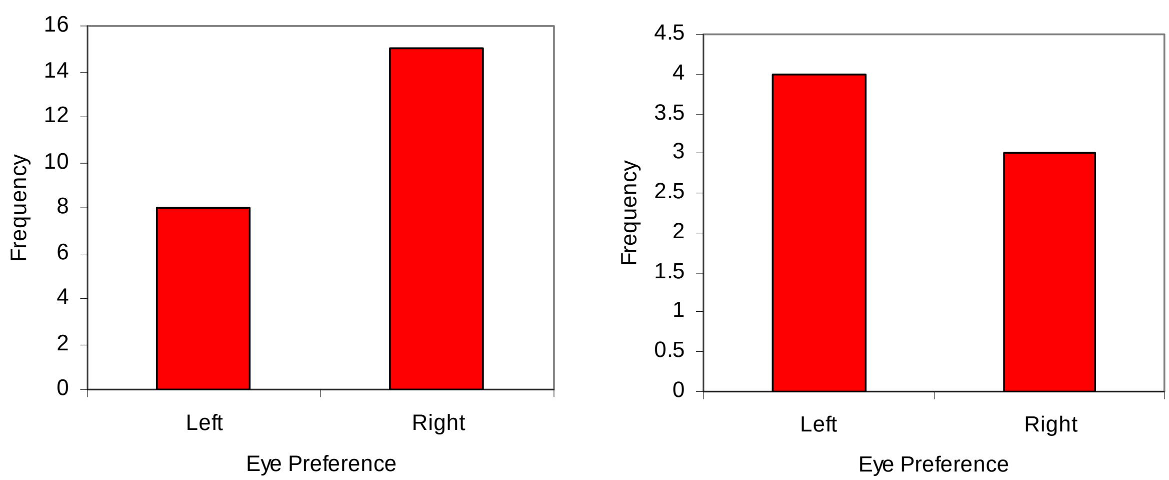

Figure 23. Eye preference distribution for control (left) and exposed (right) subjects.

Each group demonstrated different preferences for the "hole" dominance test, with a larger proportion of the control group preferring the right eye and a larger proportion of the exposed group preferring the left eye. However, the difference in these proportions was not statistically significant (p = .290). The right-eye trend in the proportion for control subjects agrees with the eye preference question in the vision history section (Question 17) of the annual questionnaire, where 61% of subjects reported a right-eye preference. However, the left-eye trend in the proportion for exposed subjects disagrees with the eye preference, where 86% of subjects

reported a right-eye preference. Three exposed subjects who previously indicated right-eye preference were found to be left-eye dominant using the “hole” test. This is not a surprising phenomenon. First, eye dominance itself is not a singularly defined concept and is task dependent. Second, each of the three exposed subjects whose most recent “hole” test data indicate a discrepancy between stated eye preference did not present this discrepancy in years prior.

Within-subject analyses (Exposed)

An obligatory objective of this report is to ensure that no evidence exists indicating that exposed subjects are being harmed (i.e., reduction in visual function) by the use of the monocular IHADSS HMD. To meet this objective, repeated-measures (within-subject) ANOVAs on exposed subject data were performed where deemed necessary based on between-subject analyses using the data obtained during the annual eye examinations. Where missing data precluded the use of ANOVAs, paired-samples *t*-tests were applied using the first and last available data values for each subject over individual exposure periods. No within-subject analyses were performed with questionnaire data on visual symptoms and problems, eye fatigue, etc., since no between-subject differences were found to be statistically significant for any of these parameters.

For those parameters in which each eye is tested separately, an alternative analysis was conducted comparing left versus right eye scores. In these analyses, a metric referred to as an interocular difference (IOD) score was calculated for each subject for initial and final data measurements using right and left eye scores. The IOD metric has the advantage that it factors out environmental and testing procedure confounds that may be present over the exposure period. One aspect of this metric is that it takes advantage of the unique IHADSS HMD scenario where the left eye serves as a control for the right eye exposed to the HMD imagery.

Refractive error

A one-way repeated-measures ANOVA of the exposed group was conducted with the factor being number of years of IHADSS exposure and the dependent variable being spherical equivalent refractive error. Only five subjects were used in the analysis; for one of these subjects, one data point was extrapolated. The remaining two subjects had multiple years of missing autorefractor data and were not included in the analysis.

The means and standard deviations for spherical equivalent refractive error scores are presented in Table 5. The results for the ANOVA indicate no significant exposure effect for either eye: right eye, Wilks’ $\Lambda = 0.764$, $F(3,12) = 0.206$, $p = .885$, multivariate $\eta^2 = 0.236$; left eye, Wilks’ $\Lambda = 0.666$, $F(3,12) = 0.334$, $p = .807$, multivariate $\eta^2 = 0.334$.

In order to utilize data from all seven exposed subjects, a paired-samples *t-test* was conducted to evaluate whether there was a significant difference in spherical equivalent refractive error scores between the first and last measured scores for each eye for exposed subjects. The results indicated that the mean for the first measurement for the right eye ($M = -0.34$, $SD = 1.23$) was

not statistically significantly different from the mean for the last measurement (*M* = -0.52, *SD* = 1.22), *t*(6) = 1.37, *p* = .221. The average exposure time between first and last measurements was 2.6 years. The mean difference in dioptres was 0.18 between the two scores for the right eye, and there was considerable overlap in the distributions for the two scores, as shown in Figure 24.

Table 5.
Means and standard deviations for exposed subject spherical equivalent refractive error (*n* = 5).

	Right eye (OD)		Left eye (OS)	
Years of exposure	*M*	*SD*	*M*	*SD*
1	-0.575	1.380	-0.600	1.137
2	-0.800	1.342	-0.625	1.086
3	-0.700	1.430	-0.525	1.181
4	-0.725	1.424	-0.649	1.148

For the left eye, the first measurement (*M* = -0.39, *SD* = 1.00) was not statistically significantly different from the mean for the last measurement (*M* = -0.43, *SD* = 1.02), *t*(6) = 0.34, *p* = .747. The average exposure time between first and last measurements was 2.6 years. The mean difference in dioptres was 0.04 between the two scores for the left eye, and there was considerable overlap in the distributions for the two scores, as shown in Figure 24.

Individual scores for both right and left eyes plotted over exposure time are presented in Figure 25.

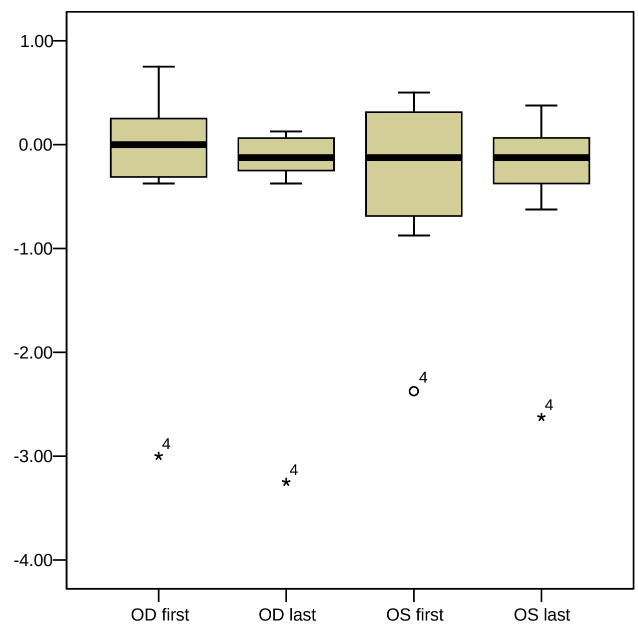

Figure 24. Box plots of first and last measured spherical equivalent refractive error scores for right (OD) and left (OS) eyes for exposed subjects.

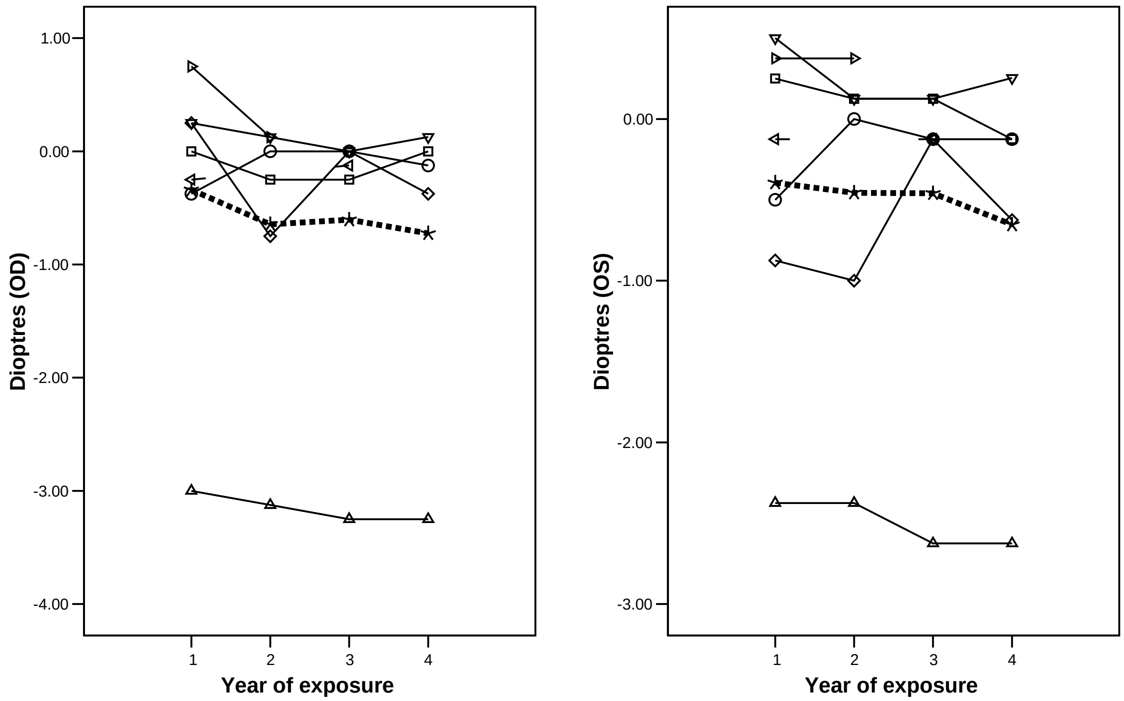

Figure 25. Spherical equivalent refractive error across years for right (OD) and left (OS) eyes for exposed subjects.
Note: Mean scores are represented with dotted lines.

An alternative investigation is to compare left versus right eye scores using the IOD metric. The mean IOD scores were -0.05 and 0.08 for initial and final measurements, respectively. Negative IOD scores imply that the right eye value was larger (i.e., more myopic) than that for the left eye. When tested via an independent-samples *t-test*, the two means were not found to be statistically different, $p = .181$.

Bailey-Lovie high contrast visual acuity

For clinical interpretation, logMAR scores were determined using the formula logMAR = -0.3 + N(0.02) where N is the number of letters missed (one letter corresponds to a logMAR difference of 0.02). Conversion from logMAR to Snellen acuity is accomplished using the formula to determine the Snellen denominator: $(20/xx) = 20 \times 10^{\text{logMAR}}$. Note that the higher (or more plus) the logMAR value, the lower the performance.

Due to multiple missing endpoint data values, a paired-samples *t-test* was conducted to evaluate whether there was a significant difference in Bailey-Lovie high contrast visual acuity logMAR scores between the first and last measured scores for each eye for exposed subjects. The results indicated that the mean for the first measurement for the right eye ($M = .024$, $SD = 0.14$) was statistically significantly different than the mean for the last measurement ($M = 0.13$, $SD = 0.06$), $t(6) = 2.64$, $p = .039$. The average exposure time between first and last measurements was 2.6 years. Although the difference is significant, it is indicative of improved

performance on the test over the period of exposure. The mean logMAR difference was 0.11 (corresponding to approximately five letters or one row on the test chart) between the two scores for the right eye, and there was little overlap in the distributions for the two scores, as shown in Figure 26.

For the left eye, the first measurement (M = 0.19, SD = 0.12) was also statistically significantly different than the mean for the last measurement (M = 0.13, SD = 0.10), $t(6) = 4.86$, p = .003. The average exposure time between first and last measurements was 2.6 years. As with the right eye, this difference is also indicative of improved performance. The mean logMAR difference was 0.06 (corresponding to approximately three letters) between the two scores for the left eye, and there was considerable overlap in the distributions for the two scores, as shown in Figure 26.

Individual scores for both right and left eyes plotted over exposure time are presented in Figure 27. A possible explanation for improved performance is an increased awareness among subjects over the 2.6 year period the data represents of the need to wear better spectacle or contact lens correction.

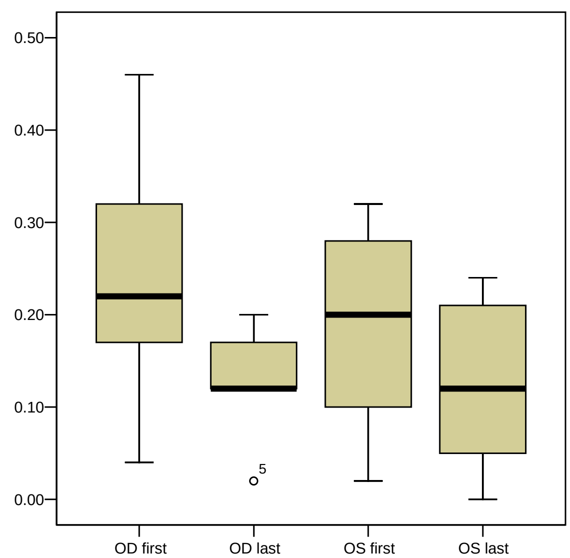

Figure 26. Boxplots of first and last measured Bailey-Lovie high contrast visual acuity scores for right (OD) and left (OS) eyes for exposed subjects.

Even though the statistically significant difference between initial and final scores for each eye represented improvements in performance, it was considered of interest to compare differences between the left (unaided) and right (IHADSS-aided) eyes over the exposure times. To investigate this, difference scores were calculated for each subject for each eye using initial and final data values. The mean differences within eyes were -0.06 and -0.11 for the left and right eyes, respectively. When tested via an independent-samples *t-test*, the two means were not found to be statistically different, p = .161.

An alternative investigation is to compare left versus right eye scores using the IOD metric. The mean IOD scores between eyes were -0.06 and -0.01 for initial and final measurements, respectively. Negative IOD scores imply that the right eye value was larger than that for the left eye. When tested via an independent-samples *t*-test, the two means were not found to be statistically different, $p = .396$.

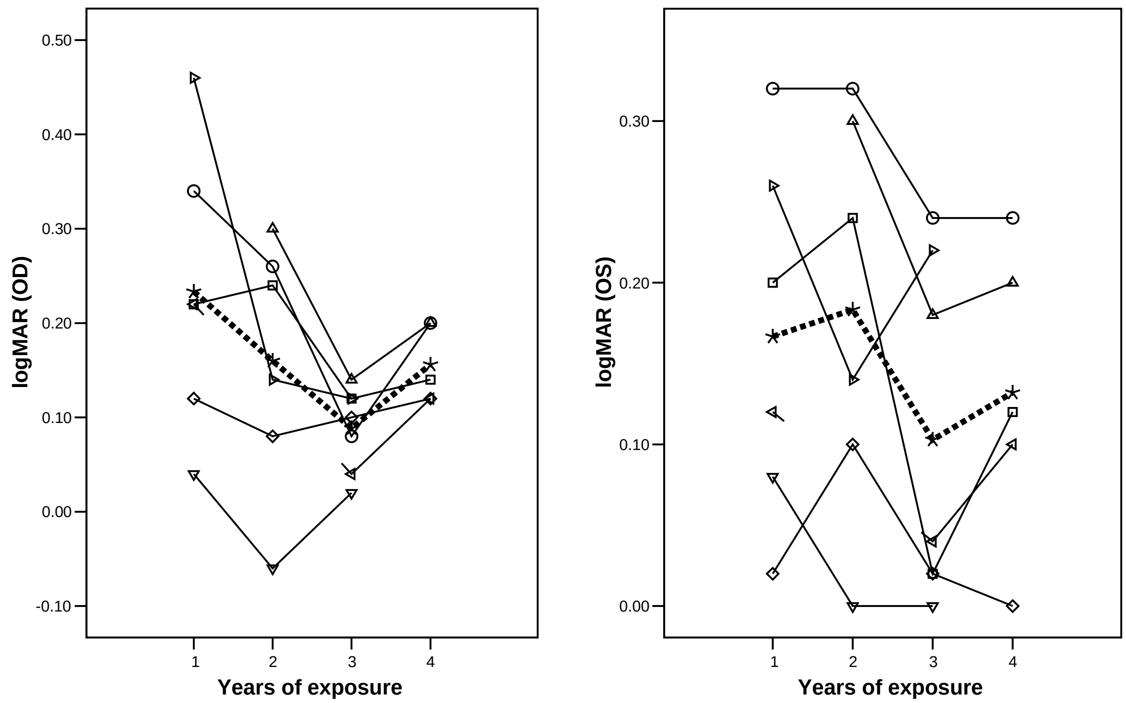

Figure 27. High contrast visual acuity across years for right (OD) and left (OS) eyes for exposed subjects.
Note: Mean scores are represented with dotted lines.

Bailey-Lovie low contrast visual acuity

Due to multiple missing endpoint data values, a paired-samples *t-test* was conducted to evaluate whether there was a significant difference in Bailey-Lovie low contrast visual acuity logMAR scores between the first and last measured scores for each eye for exposed subjects. The results indicated that the mean for the first measurement for the right eye ($M = 0.44$, $SD = 0.10$) was not statistically significantly different from the mean for the last measurement ($M = 0.43$, $SD = 0.07$), $t(6) = 0.60$, $p = .570$. The average exposure time between first and last measurements was 2.1 years. The mean logMAR difference was 0.01 (corresponding to less than one letter) between the two scores for the right eye, and there was considerable overlap in the distributions for the two scores, as shown in Figure 28.

For the left eye, the first measurement ($M = 0.45$, $SD = 0.11$) was again not statistically significantly different from the mean for the last measurement ($M = 0.43$, $SD = 0.08$), $t(6) = 0.87$, $p = .417$. The average exposure time between first and last measurements was 2.1 years. The mean logMAR difference was 0.03 (corresponding to less than approximately two letters)

between the two scores for the left eye, although there was minor overlap in the distributions for the two scores, as shown in Figure 28.

Individual scores for both right and left eyes plotted over exposure time are presented in Figure 29.

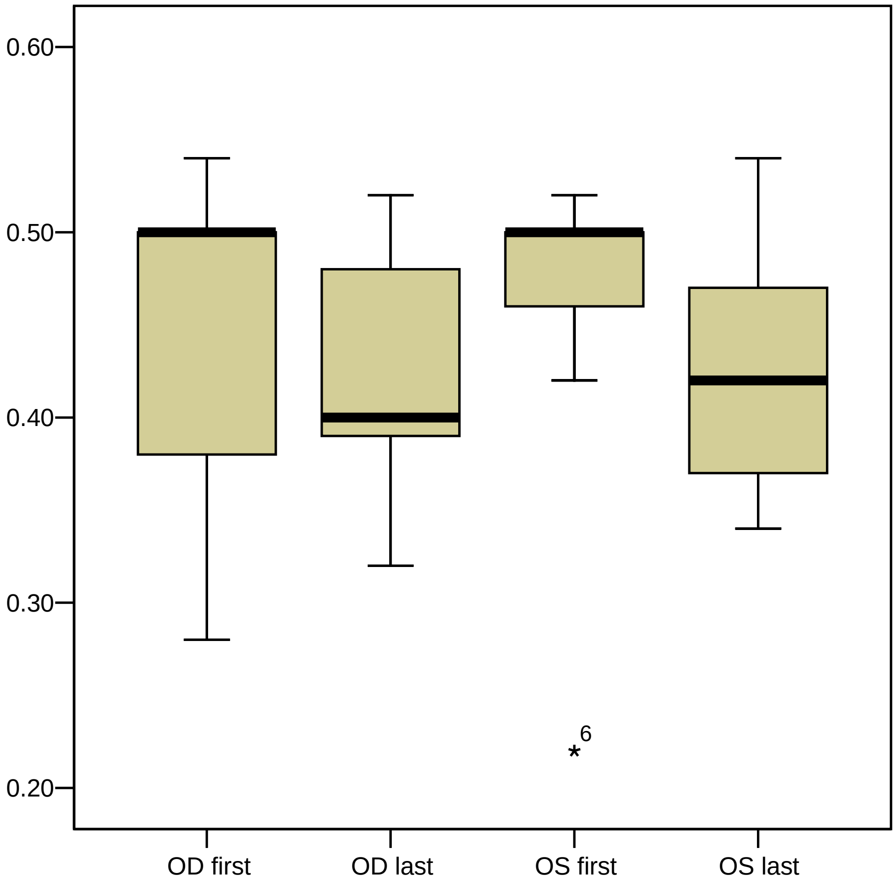

Figure 28. Box plots of first and last measured Bailey-Lovie low contrast visual acuity scores for right (OD) and left (OS) eyes for exposed subjects.

An alternative investigation is to compare left versus right eye scores using the IOD metric. The mean IOD scores were 0.01 and 0.00 for initial and final measurements, respectively. Negative IOD scores imply that the right eye value was larger than that for the left eye. When tested via an independent-samples *t-test*, the two means were not found to be statistically different, p =.332.

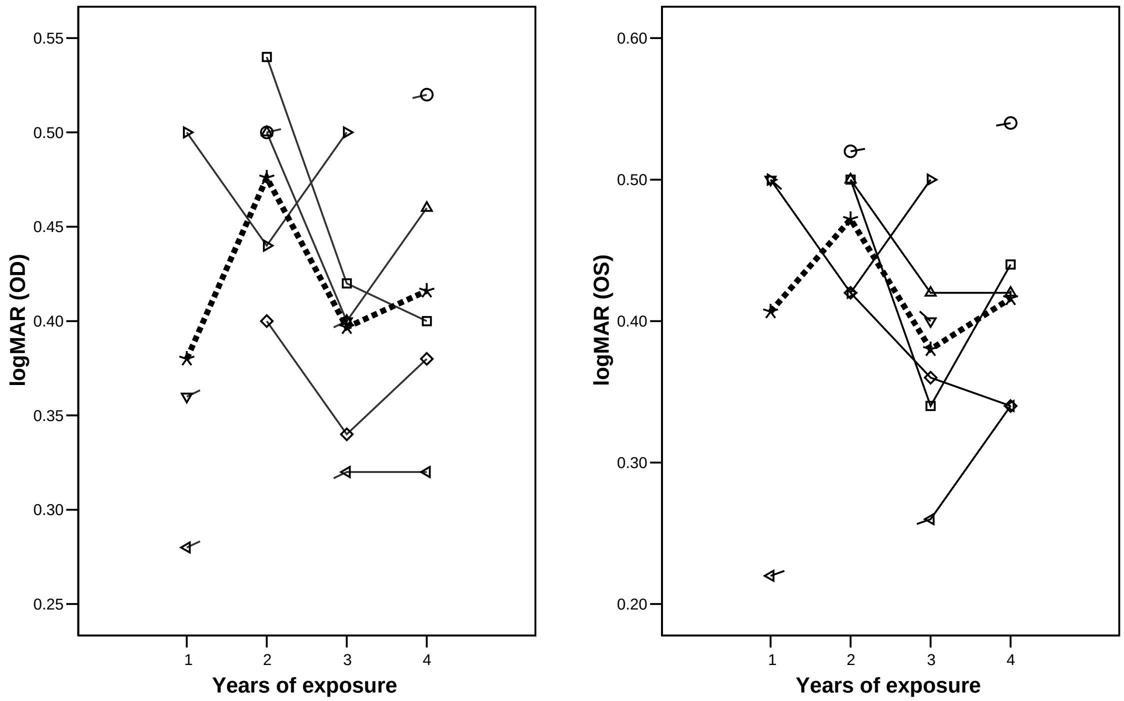

Figure 29. Low contrast visual acuity across years for right (OD) and left (OS) eyes for exposed subjects. Note: Mean scores are represented with dotted lines.

Small letter contrast sensitivity

The measured data value is the total number of incorrect (unreadable) letters. Each score is converted into a meaningful value of logCS using the formula logCS = 1.3 – N(0.01), where N is the total number of missed letters. The mean expected score on this test is logCS = 1.1.

Due to multiple missing endpoint data values, a paired-samples *t-test* was conducted to evaluate whether there was a significant difference in small letter contrast sensitivity logCS scores between the first and last measured scores for each eye for exposed subjects. The results indicated that the mean for the first measurement for the right eye (M = 0.80, SD = 0.28) was not statistically significantly different from the mean for the last measurement (M = 0.92, SD = 0.19), $t(6)$ = -1.66, p = .147. The average exposure time between first and last measurements was 2.6 years. The mean logCS difference was 0.12 (corresponding to approximately 12 letters or over one row on the test chart) between the two scores for the right eye, and there was considerable overlap in the distributions for the two scores, as shown in Figure 30.

For the left eye, the first measurement (*M* = 0.80, *SD* = 0.23) was not statistically significantly different from the mean for the last measurement (*M* = 0.93, *SD* = 0.23), $t(6) = -1.44$, $p = .199$. The average exposure time between first and last measurements was 2.6 years. The mean logCS difference was 0.13 (corresponding to approximately 13 letters or over one row on the test chart) between the two scores for the left eye, and there was considerable overlap in the distributions for the two scores, as shown in Figure 30.

Individual scores for both right and left eyes plotted against time are presented in Figure 31. (Note: The lower outlier values for both eyes of one subject are most likely due to failure of subject to have corrective eyewear available during first exam.)

An alternative investigation is to compare left versus right eye scores using the IOD metric. The mean IOD scores were 0.00 and 0.01 for initial and final measurements, respectively. When tested via an independent-samples *t-test*, the two means were not found to be statistically different, $p = .383$.

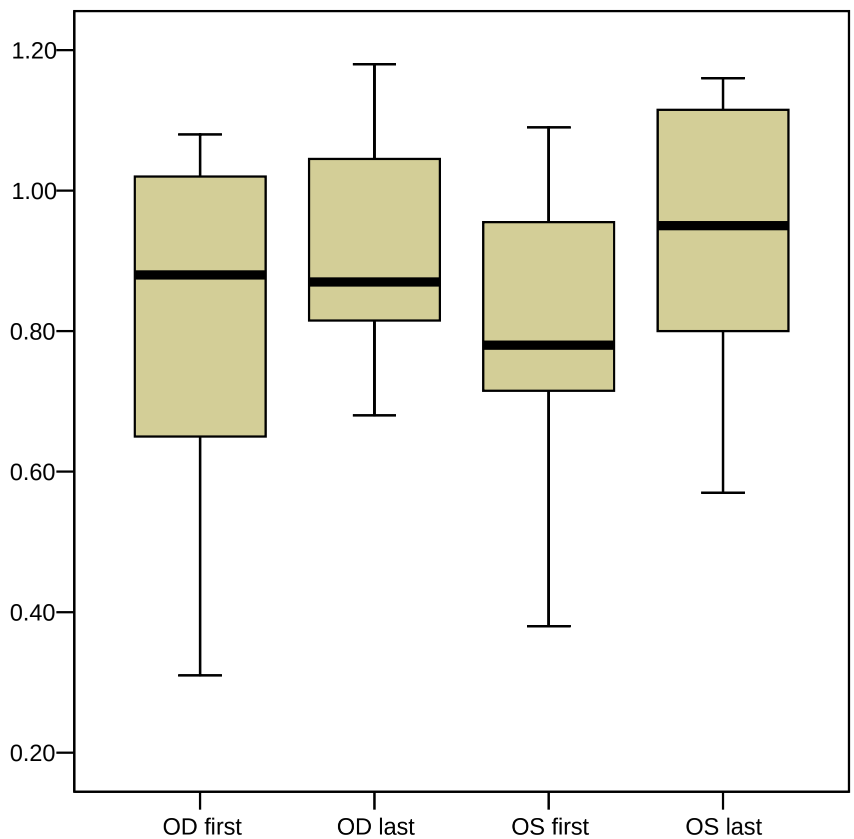

Figure 30. Box plots of first and last measured small letter contrast sensitivity scores for right (OD) and left (OS) eyes for exposed subjects.

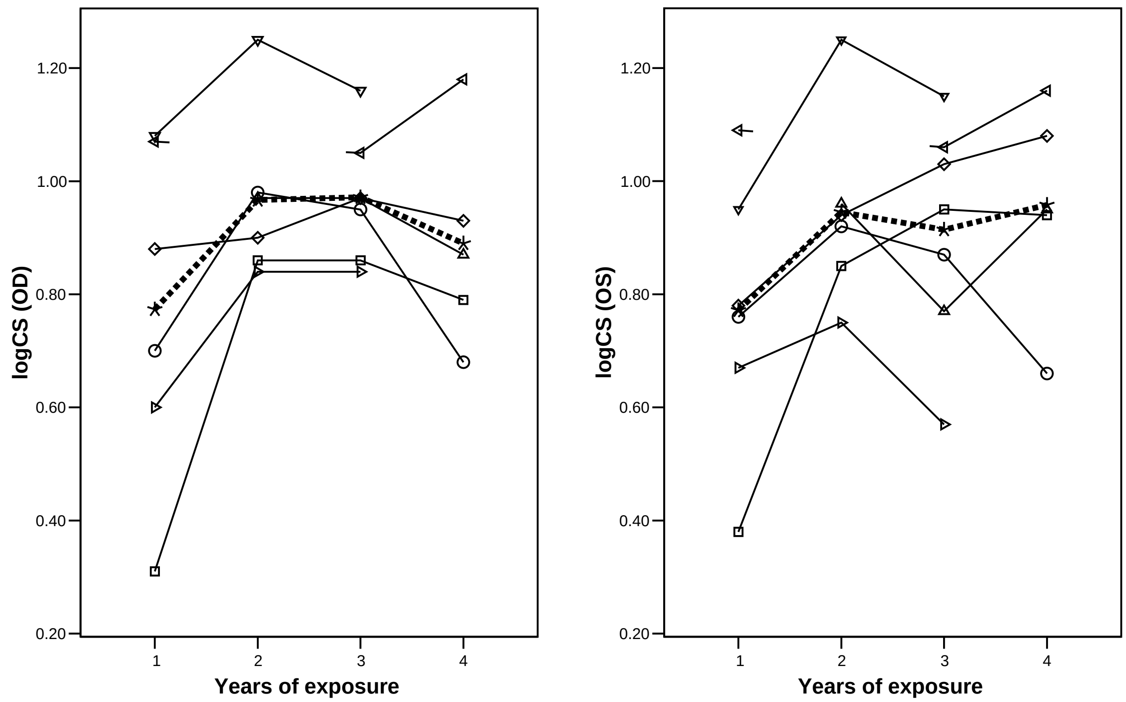

Figure 31. Small letter contrast sensitivity across years for right (OD) and left (OS) eyes for exposed subjects.
Note: Mean scores are represented with dotted lines.

Depth perception

A one-way repeated-measures ANOVA of the exposed group was conducted with a factor being number of years of IHADSS exposure and the dependent variable being depth perception scores (in seconds of arc). Only four subjects had complete data points; one data point was interpolated for two subjects; one data point was extrapolated for the seventh subject.

The means and standard deviations for spherical equivalent refractive error scores are presented in Table 6; time plots are presented in Figure 32. The results for the ANOVA indicate no significant exposure effect, Wilks' $\Lambda = 0.714$, $F\,(3,12) = 0.533$, $p = .684$, multivariate $\eta^2 = 0.286$.

Table 6.
Means and standard deviations for exposed subject depth perception scores (n = 7).

Years of exposure	*M*	*SD*
1	25.71	1.890
2	24.64	2.249
3	25.71	1.890
4	25.00	2.887

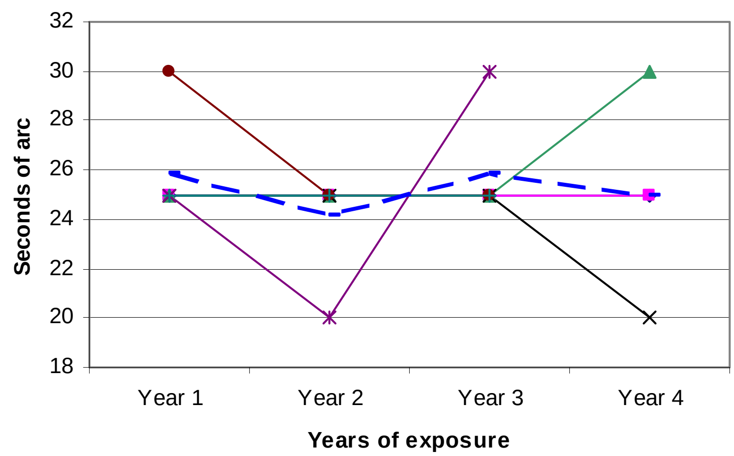

Figure 32. Depth perception scores across years for exposed subjects.
Note: Mean score is represented with a dotted line.

Color perception

A one-way repeated-measures ANOVA of the exposed group was conducted with a factor being number of years of IHADSS exposure and the dependent variable being L'Anthony desaturated D-15 color perception scores. Only four subjects had complete data points; one data point was interpolated for two subjects; one data point was extrapolated for the seventh subject.

The means and standard deviations for L'Anthony desaturated D-15 color perception scores are presented in Table 7; time plots are presented in Figure 33. The results for the ANOVA indicate no significant exposure effect for either eye: right eye, Wilks' $\Lambda = 0.691$, $F(3,12) = 0.597$, $p = .650$, multivariate $\eta^2 = 0.309$; left eye, Wilks' $\Lambda = 0.581$, $F(3,12) = 0.960$, $p = .493$, multivariate $\eta^2 = 0.419$.

Table 7.
Means and standard deviations for exposed subject L'Anthony desaturated D-15 color perception scores ($n = 7$).

	Right eye (OD)		Left eye (OS)	
Years of exposure	*M*	*SD*	*M*	*SD*
1	63.200	6.595	58.543	4.027
2	62.086	7.868	62.829	5.826
3	67.171	11.883	66.600	15.700
4	63.876	11.138	64.900	16.612

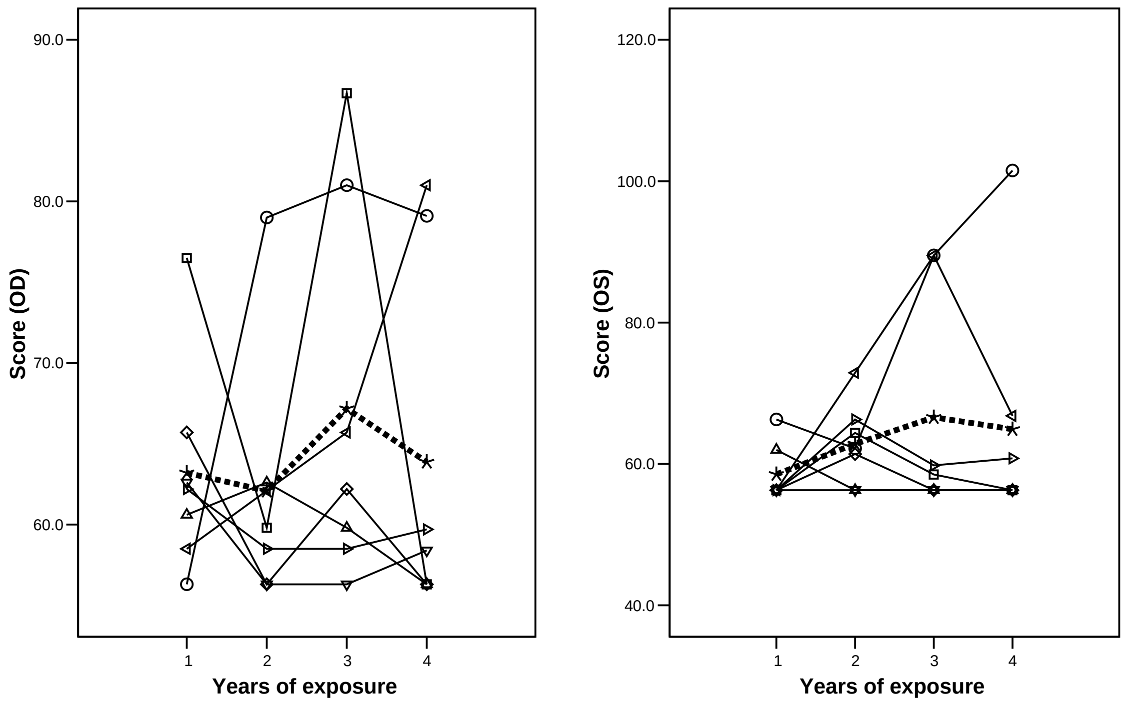

Figure 33. Color perception scores across years for right (OD) and left (OS) eyes for exposed subjects.
Note: Mean scores are represented with dotted lines.

An alternative investigation is to compare left versus right eye scores using the IOD metric. The mean IOD scores were -4.66 and 1.03 for initial and final measurements, respectively. Negative IOD scores imply that the right eye value was larger than that for the left eye. When tested via an independent-samples *t-test*, the two means were not found to be statistically different, $p = .903$.

Accommodation

Due to multiple missing endpoint data values, a paired-samples *t-test* was conducted to evaluate whether there was a significant difference in accommodative power between the first and last measured values for each eye for exposed subjects. The results indicated that the mean for the first measurement for the right eye ($M = 8.30$, $SD = 4.24$) was not statistically significantly different from the mean for the last measurement ($M = 4.68$, $SD = 1.63$), $t(6) = 2.38$, $p = .055$. The average exposure time between first and last measurements was 2.6 years. The mean difference in accommodative power was 3.62 between the two values for the right eye, and there was little overlap in the distributions for the two scores, as shown in Figure 34.

Similarly for the left eye, the first measurements ($M = 7.92$, $SD = 4.18$) was not statistically significantly different from the last measurements ($M = 4.58$, $SD = 1.50$), $t(6) = 2.14$, $p = .076$. The mean difference in accommodative power was 3.34 between the two values for the left eye,

and there was little overlap in the distributions for the two scores, as shown in Figure 34. Individual scores for both right and left eyes plotted against time are presented in Figure 35.

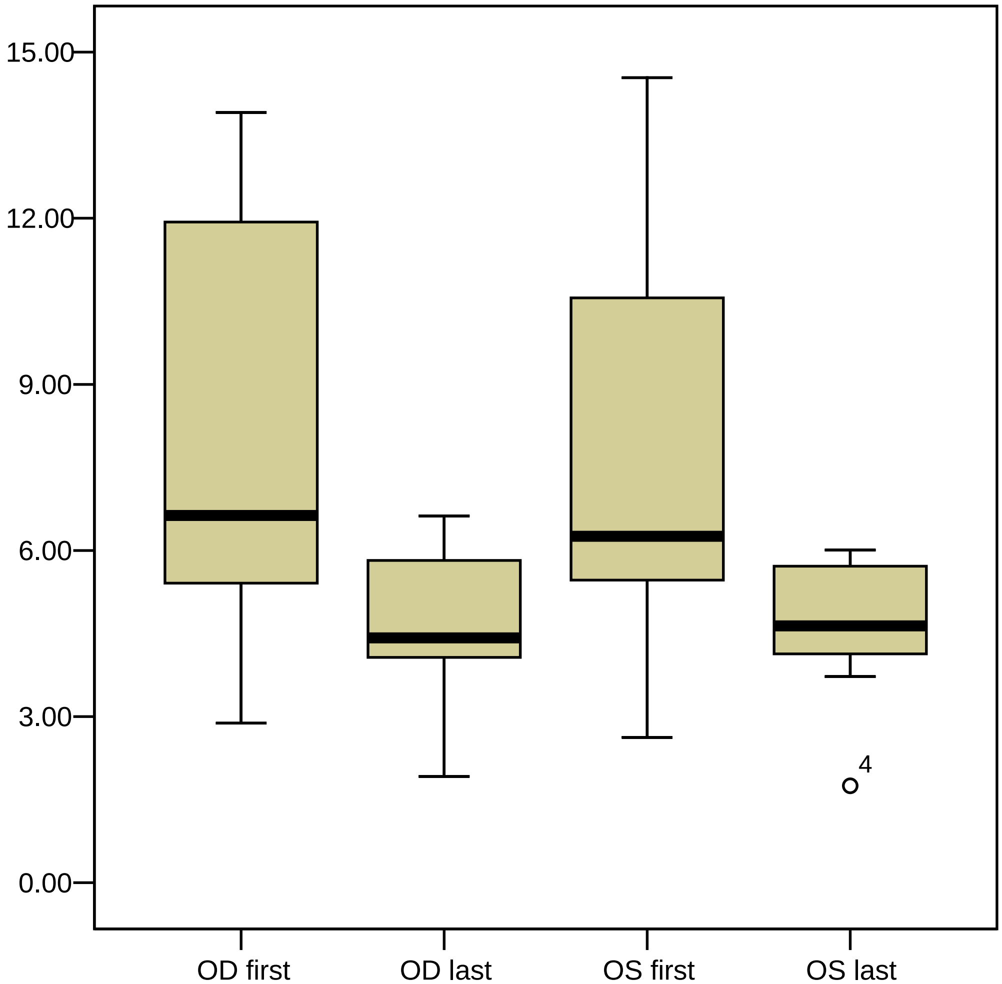

Figure 34. Box plots of first and last measured accommodative power for right (OD) and left (OS) eyes for exposed subjects.

An alternative investigation is to compare left versus right eye scores using the IOD metric. The mean IOD scores were -0.38 and 0.09 for initial and final measurements, respectively. Negative IOD scores imply that the right eye value was larger than that for the left eye. When tested via an independent-samples *t-test*, the two means were not found to be statistically different, $p = .107$.

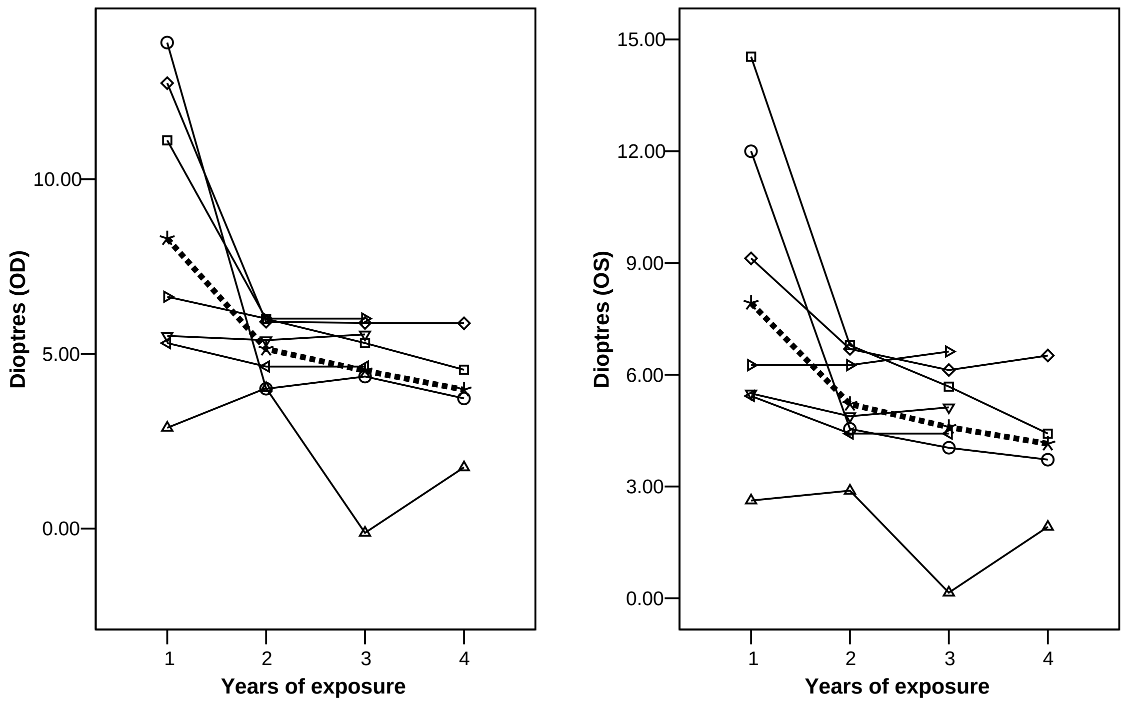

Figure 35. Accommodative power across years for right (OD) and left (OS) eyes for exposed subjects. Note: Mean scores are represented with dotted lines.

Eye preference

Three of the seven exposed subjects were measured as having right-eye sighting dominance over the entire reporting period (although one of these subjects was only measured for three years). Another three subjects demonstrated a reversal in the sighting dominance eye, switching from right- to left-eye dominance, for the last examination. The last subject, having data only for three years, presented findings that alternated between left-, right-, and then back to left-eye dominance. Therefore, based on the last examination data available for each subject, four out of the seven subjects (57%) were found to have switched dominant eye.

When these data are investigated as a function of exposure time, the percentage of right-eye dominance, as presented in Figure 36, decreases greatly for the last examination cycle.

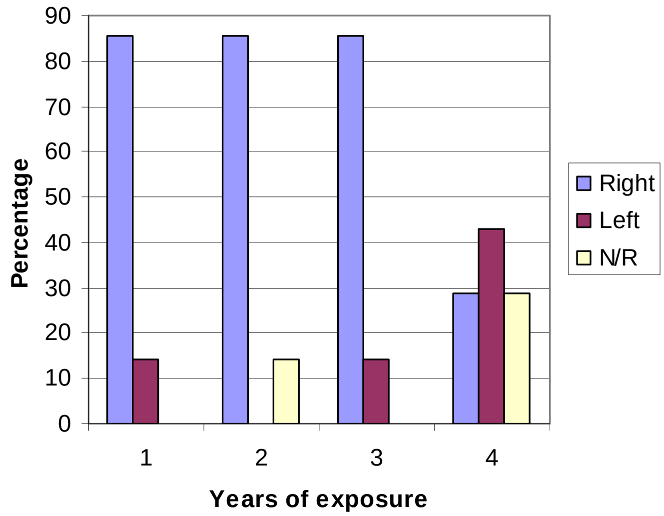

Figure 36. Eye dominance as a function of exposure time.

Discussion and conclusions

The original study design called for a projection of 80 exposed and 300 control subjects by the midpoint (end of fifth year) of the study. Considering the one year delay, data collection is in its third year and projected enrollment should be 48 exposed and 180 control subjects. Therefore, the current study enrollment of 53 exposed subjects meets the projection; while the total of 136 control subjects fails to do so. In the last two years, considerable effort was focused on increasing the exposed sample size, a deficiency noted in the two-year report. This effort was successful but may have been at the expense of the control sample.

For the full study enrollment, the mean age of the control subjects (31 years) remained the same, while the mean age for exposed subjects decreased from 39 years to 35 years. This difference between exposed and control mean ages, although decreasing, was still statistically significant ($p < .001$). Similarly, for total flight hours, the mean for control subjects increased only slightly from 805 to 909 hr, while the mean for exposed subjects decreased from 3720 to 2358 hr. Although this difference is decreasing, the difference was still statistically significant ($p < .001$).

For the subjects considered in this four-year analysis, the total number of control (non-Apache) subjects enrolled as of 31 December 2004 was 23. Control subjects ranged in age from 23 to 51 years with a mean and median each of 36 years. The total flight hours for the control group ranged from 370 to 8400, with a mean and median of 2121 and 1460 hr, respectively.

The total number of exposed (Apache) included in this four-year analysis was seven. Exposed subjects ranged in age from 35 to 48 years, with a mean and median of 40 and 39 years, respectively. The total flight hours for the exposed group ranged from 2330 to 7250, with a mean and median of 3746 and 3200 hr, respectively. Total flight hours in the Apache ranged

from 150 to 820, with a mean and median of 446 and 450 hr, respectively. Flight time using the IHADSS had a mean and median of 442 and 379 hr, respectively.

When the two subject groups were compared, both groups were predominately male (exposed -100%; control - 91%). The exposed group was older (mean age of 40 years vs. 36 years for control group), but this difference was not statistically significant ($p = .247$). There also was a lack of significance between total flight hours, where the mean exposed total flight hours was 3746, versus 2121 hr for control subjects ($p = .078$). However, the difference in the total number of flights hours using the respective night vision devices was statistically significant (IHADSS = 442 hr vs. NVG = 117 hr, $p < .001$).

At the current four-year stage (which analyzes three years of data), there are no statistically significant differences between the exposed and control groups for vision history, visual problems, or eye examination visual parameters.

For flight-related visual problems, headache continues to be the most frequently reported symptom both *during* and *after* flight. Two-way contingency table analyses were conducted to evaluate differences in symptom reports for control and exposed subjects and for *during* or *after* flight conditions. No statistically significant differences were found for headache, disorientation and visual discomfort with the p-value was set at the $p < .05$ level. However, when the frequencies of afterimages *after* flight were evaluated, a statistically significant difference was found ($\chi^2 = 5.83$; $p = .016$), with 29% ($n = 2$) of exposed subjects reporting sometimes experiencing afterimages versus 9% ($n = 2$) of control subjects.

With monocular HMDs, i.e., the IHADSS, a more complex visual situation is presented. Since only one eye views the display, the brightness difference between the images presented to the two eyes can be quite large. While the other binocular alignment problems are not present, perceptual issues relating to conflicting left- and right-eye images can cause eye fatigue. The major of these issues is binocular rivalry (Rash, Verona and Crowley, 1990). The response to one eye viewing the monochromatic green video image and the other eye viewing a dark cockpit and the outside world can be suppression of the eye viewing the dimmer cockpit and outside world. Viewing these dissimilar images has proven to be especially fatiguing during lengthy missions. Voluntary switching between the two images has been reported as difficult by some aviators. In addition, these competing images can lead to involuntary switching of attention, due to binocular rivalry (Melzer and Moffitt, 1997). However, there also was no significant difference found in self-reported eye fatigue between the two groups.

Eye examination (Between-subject)

The mean spherical equivalent refractive error for controls was essentially zero, equivalent to emmetropia, while the exposed group had a mean spherical equivalent refractive error in the myopia range: -0.75 for the right eyes and -0.68 for left eyes. These differences were not statistically significant (right eyes, $p = .085$; left eyes, $p = .075$). These numerical differences are most likely due to the difference in age of the two groups, in keeping with there being a trend toward increasing myopia with age (there was a four-year difference between group mean ages).

Visual acuity is an important measure of visual capability of pilots. While visual acuity was expected to be 6/6 (20/20) or better (0.00 logMAR) for this population, the actual measures were closer to 6/7.5 (20/24 or 0.08 logMAR) for the control subjects and 6/8 (20/27 or 0.12 logMAR) for exposed subjects. This reduced acuity was a consequence of measurements using each pilot's own eyeglasses, which may or may not be current, or for those subjects reporting for testing without glasses or low amounts of uncorrected refractive error. Based on the Bailey-Lovie tests, there were not statistically significant differences in either the high contrast visual acuity (right eyes, $p = .06$; left eyes, $p = .23$) or the low contrast visual acuity (right eyes, $p = .42$; left eyes, $p = .36$) of the two groups for either right or left eyes.

Retinal sensitivity, a factor in the ability to see low contrast letters (measured by the SLCT), also declines with age; however, the same general trends apply as seen with optical changes with age. There was not a statistically significant difference between groups for the SLCT results (right eyes, $p = .15$; left eyes, $p = .28$).

The mean depth perception scores for the control and exposed groups represent excellent depth perception; 40 seconds of arc or better is the standard for U.S. Army aviators. Only one control subject performed worse than this standard. There was not a statistically significant difference between the groups ($p = .728$).

On average, exposed subjects had only a slightly lower (better) color perception score than control subjects. The three control subjects who were outside the norms for color perception may have mild to moderate levels of color deficiency. Among the exposed subjects, two were outside the norms for color perception and also may have mild levels of color deficiency. However, there was not a statistically significant difference between the groups (right eyes, $p = .842$; left eyes, $p = .911$).

Accommodation test results were broken down according to age, since accommodative capability naturally decreases with age. The control group included younger subjects between the ages of 20 and 29 years; there were no subjects in this age range for the exposed group. There was not a statistically significant difference between groups for the 30 to 39 year olds (right eyes, $p = .53$; left eyes, $p = .72$) or for the 40 to 49 year olds (right eyes, $p = .70$; left eyes, $p = .57$).

Eye muscle balance was measured for both a <u>distance</u> (6 m [20 ft]) and <u>near</u> (~½ m [18 in]) condition. Twenty control subjects were measured. All subjects had a measurable heterophoria at <u>distance</u>; 17 (85%) were esophoric, three (15%) were exophoric and 10 (50%) were also hyperphoric. Esophoria ranged from 1 to 8 prism dioptres; exophoria ranged from 1 to 2 prism dioptres; and hyperphoria ranged from 0.25 to 1 prism dioptre. All subjects had a measurable heterophoria at <u>near</u>; 16 (80%) were esophoric, three (15%) were exophoric and 13 (65%) were also hyperphoric; one subject (5%) only had hyperphoria. Esophoria ranged from 1 to 11 mean prism dioptres; exophoria ranged from 1 to 2 mean prism dioptres; and hyperphoria ranged from 0.5 to 1.5 mean prism dioptres.

All seven exposed subjects had a measurable heterophoria at <u>distance</u>; all (100%) were esophoric and five (71%) were also hyperphoric. Esophoria ranged from 2 to 7 prism dioptres

and hyperphoria was 0.5 prism dioptres. All subjects (100%) were esophoric at near and 6 (85%) were also hyperphoric. Esophoria ranged from 1 to 8 mean prism dioptres and hyperphoria ranged from 0.5 to 1.5 mean prism dioptres.

Heterophoria is a measure of the solidness of ocular alignment and binocular fusion to a target at a given distance. For both groups, esophoria was the most common condition for both distant and near targets. The movement toward esophoria demonstrated by both groups as compared to the two-year report was very likely a result of the replacement of equipment for this test. Only three control subjects had exophoria, a divergence tendency, for distant or near viewing. The distribution of heterophorias was very similar for both groups and was not statistically different between groups (distance, $p = .28$; near, $p = .21$).

Each group demonstrated different preferences for dominance, using the "hole" test, with a larger proportion of the control group preferring the right eye and a larger proportion of the exposed group preferring the left eye. However, the difference in these proportions was not statistically significant ($p = .290$). The right-eye trend in the proportion for control subjects agrees with the eye preference question in the vision history section of the annual questionnaire, where 61% of subjects reported a right-eye preference. However, the left-eye trend in the proportion for exposed subjects disagrees with the eye preference, where 86% of subjects reported a right-eye preference. Three exposed subjects who previously indicated right-eye preference were found to be left-eye dominant using the "hole" test. This is not a surprising phenomenon. First, eye dominance itself is not a singularly defined concept and is task dependent. Second, each of the three exposed subjects whose most recent "hole" test data indicate a discrepancy between stated eye preference did not present this discrepancy in years prior.

Eye examination (Within-subject)

The primary objective of the ongoing study is to investigate whether or not long-term use of the monocular IHADSS HMD is degrading visual function. To meet this objective, repeated-measures (within-subject) ANOVAs on exposed subject data were performed where applicable. Where missing data precluded the use of ANOVAs, paired-samples *t-test*s were applied using the first and last available data values for each subject over individual exposure periods.

For those parameters in which each eye is tested separately, an alternative analysis was conducted comparing left versus right eye scores. In these analyses, a metric referred to as an interocular difference (IOD) score was calculated for each subject for initial and final data measurements using right and left eye scores. The IOD metric has the advantage that it factors out environmental and testing procedure confounds that may be present over the exposure period. One aspect of this metric is that it takes advantage of the unique IHADSS HMD scenario where the left eye serves as a control for the right eye exposed to the HMD imagery.

For refractive error, a paired-samples *t-test* was conducted on the seven exposed subjects to evaluate whether there was a significant difference between the first and last measured scores for each eye. The mean for the first measurement for the right eye ($M = -0.34$) was not statistically significantly different from the mean for the last measurement ($M = -0.52$), $p = .221$. The mean

difference in dioptres was 0.18 between the two scores for the right eye. For the left eye, the first measurement (*M* = -0.39) also was not found to be statistically significantly different from the mean for the last measurement (*M* = -0.43), *p* = .747. The mean difference in dioptres was 0.04 between the two scores for the left eye.

In addition, an alternative analysis using the IOD metric was performed to compare left versus right eye refractive error. The mean IOD scores were -0.05 and 0.08 for initial and final measurements, respectively. Negative IOD scores imply that the right eye value was larger (i.e., more myopic) than that for the left eye. When tested via an independent-samples *t-test*, the two means were not found to be statistically different, *p* = .181.

A paired-samples *t-test* was conducted to evaluate Bailey-Lovie <u>high</u> contrast visual acuity logMAR scores between the first and last measured scores for each eye for exposed subjects. The results indicated that the mean for the first measurement for the right eye (*M* = 0.24) was statistically significantly different than the mean for the last measurement (*M* = 0.13), *p* = .039. Although the difference is significant, it is indicative of improved performance on the test over the period of exposure. For the left eye, the first measurement (*M* = 0.19) was also statistically significantly different than the mean for the last measurement (*M* = 0.13), *p* = .003. As with the right eye, this difference is also indicative of improved performance. A possible explanation for improved performance is an increased awareness among subjects of the need to wear spectacle or contact lens correction during testing.

An alternative analysis based on the IOD metric comparing left versus right eye scores was performed on the high-contrast scores. The mean IOD scores between eyes were -0.06 and -0.01 for initial and final measurements, respectively. Negative IOD scores imply that the right eye value was larger than that for the left eye. When tested via an independent-samples *t-test*, the two means were not found to be statistically different, *p* = .396.

For Bailey-Lovie <u>low</u> contrast visual acuity, a paired-samples *t-test* was between the first and last measured scores for each eye for exposed subjects. The mean for the first measurement for the right eye (*M* = 0.44) was not found to be statistically different from the mean for the last measurement (*M* = 0.43), *p* = .570. The mean logMAR difference was 0.01 (corresponding to less than one letter) between the two scores for the right eye. For the left eye, the first measurement (*M* = 0.45) was again not statistically significantly different from the mean for the last measurement (*M* = 0.43), *p* = .417. The mean logMAR difference was 0.03 (corresponding to less than approximately two letters) between the two scores for the left eye.

In addition, the IOD metric was applied to low contrast visual acuity scores. The mean IOD scores were 0.01 and 0.00 for initial and final measurements, respectively. Negative IOD scores imply that the right eye value was larger than that for the left eye. When tested via an independent-samples *t-test*, the two means were not found to be statistically different, *p* = .332.

A paired-samples *t-test* was conducted to evaluate small letter contrast sensitivity logCS scores between the first and last measured scores for each eye for exposed subjects. The results indicated that the mean for the first measurement for the right eye (*M* = 0.80) was not statistically significantly different from the mean for the last measurement (*M* = 0.92), *p* = .147. The mean

logCS difference was 0.12 (corresponding to approximately 12 letters or over one row on the test chart) between the two scores for the right eye.

For the left eye, the first measurement ($M = 0.80$) was not statistically significantly different from the mean for the last measurement ($M = 0.93$), $p = .199$. The mean logCS difference was 0.13 (corresponding to approximately 13 letters or over one row on the test chart) between the two scores for the left eye.

For depth perception, a one-way repeated-measures ANOVA of the exposed group was conducted with a factor being number of years of IHADSS exposure and the dependent variable being depth perception scores (in seconds of arc). Only four subjects had complete data points; one data point was interpolated for two subjects; one data point was extrapolated for the seventh subject. No significant exposure effect was found ($p = .684$).

A one-way repeated-measures ANOVA of the exposed group was conducted on color perception data with a factor being number of years of IHADSS exposure and the dependent variable being L'Anthony desaturated D-15 color perception scores. Only four subjects had complete data points; one data point was interpolated for two subjects; one data point was extrapolated for the seventh subject. The ANOVA found no significant exposure effect for either eye: right eye, $p = .650$; left eye, $p = .493$. An alternative investigation to compare left versus right eye scores using the IOD metric was conducted. The mean IOD scores were -4.66 and 1.03 for initial and final measurements, respectively. Negative IOD scores imply that the right eye value was larger than that for the left eye. When tested via an independent-samples *t-test*, the two means were not found to be statistically different, $p = .903$.

Accommodation effects for exposed subjects were investigated using a paired-samples *t-test*. The results indicated that the mean for the first measurement for the right eye ($M = 8.30$) was not statistically significantly different from the mean for the last measurement ($M = 4.68$), $p = .055$. The mean difference in accommodative power was 3.62 between the two values for the right eye. Similarly for the left eye, the first measurements ($M = 7.92$) were not statistically significantly different from the last measurements ($M = 4.58$), $p = .076$. The mean difference in accommodative power was 3.34 between the two values for the left eye. The high values and the resulting variability associated with the first measurements is attributed to the failure of subjects to have available their corrective eyewear for the first visual testing period. An alternative investigation using the IOD metric also was conducted. The mean IOD scores were -0.38 and 0.09 for initial and final measurements, respectively. Negative IOD scores imply that the right eye value was larger than that for the left eye. When tested via an independent-samples *t-test*, the two means were not found to be statistically different, $p = .107$.

Three of the seven exposed subjects were measured as having right-eye sighting dominance over the entire reporting period (although one of these subjects was only measured for three years). Another three subjects demonstrated a reversal in the sighting dominance eye, switching from right- to left-eye dominance, for the last examination. The last subject, having data only for three years, presented findings that alternated between left-, right-, and then back to left-eye dominance. Therefore, based on the last examination data available for each subject, four out of the seven subjects (57%) were found to have switched dominant eye. When these data were

investigated as a function of exposure time, the percentage of right-eye dominance, as presented in Figure 36, decreased greatly for the last examination cycle. Eye preference (dominance) is very task dependent and its determination is extremely sensitive to the procedure used to determine it. Therefore, it is difficult to draw a conclusion at this phase of the study as to whether this sudden change in distribution of eye preference is meaningful. It is recommended that-test administrators be particularity careful in the procedural steps as implemented for this test.

In summary, between- and within-subject data analyses failed to find any statistically significant differences in performance on the visual tests for exposed and control subjects. Of all the visual parameters evaluated over the first three years of collected data, only measures of preferred eye showed any detectable change, and this change was present only during the last measurement cycle. Its impact is unknown at this time.

In conclusion, at this phase in the study, there is no evidence that the prolonged use of the monocular IHADSS HMD has produced any meaningful differential vision changes between the two eyes. As the study progresses, we will continue to look for any trends in visual performance between eyes that may support or refute the presence of these differential changes.

Recommendations

As the study progresses towards its midpoint, it is recommended that the following issues be addressed:

a. Study administrators must take appropriate actions to increase control sample size.

b. A continuing common problem associated with this study is maintaining stringent oversight of data collection. A small percentage of study questionnaires were not completed, resulting in missing data values. A tighter oversight of questionnaire completion is recommended.

c. A high percentage of exposed subjects require vision correction. It is recommended, where appropriate, that vision tests be conducted with and without vision correction.

d. Particular attention must be paid to ensuring that the procedure used to measure eye preference be methodical from subject to subject.

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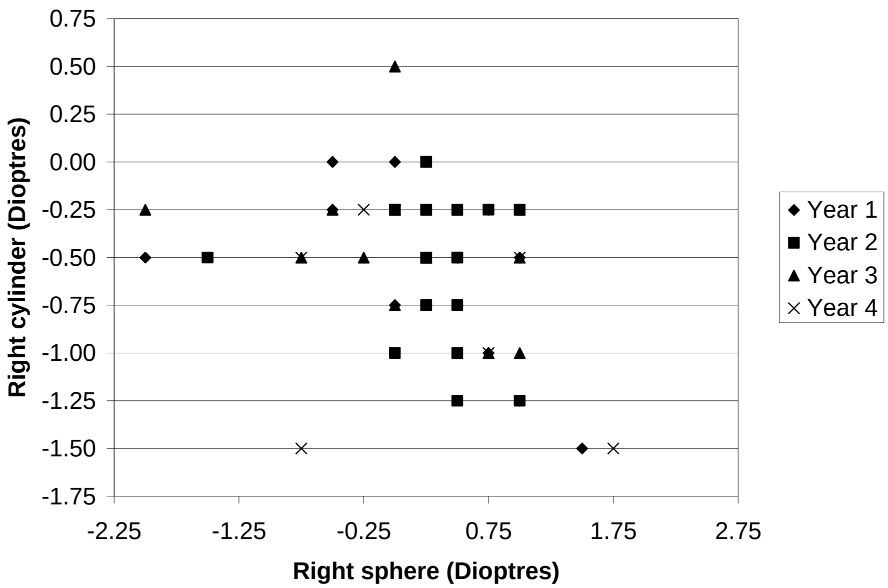
Appendix A.

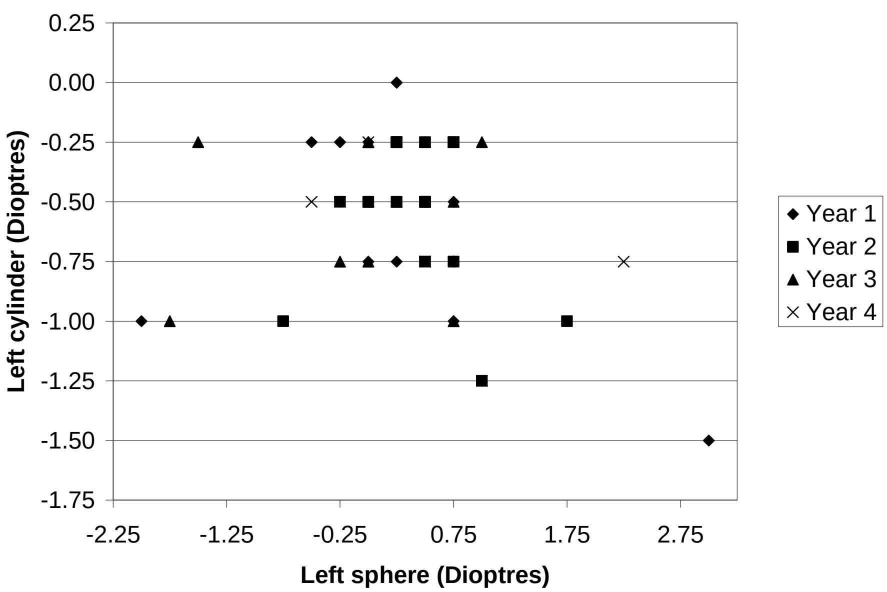
Non-Apache (Control) pilot eye examination.

(includes last-year data only)

Manual refraction

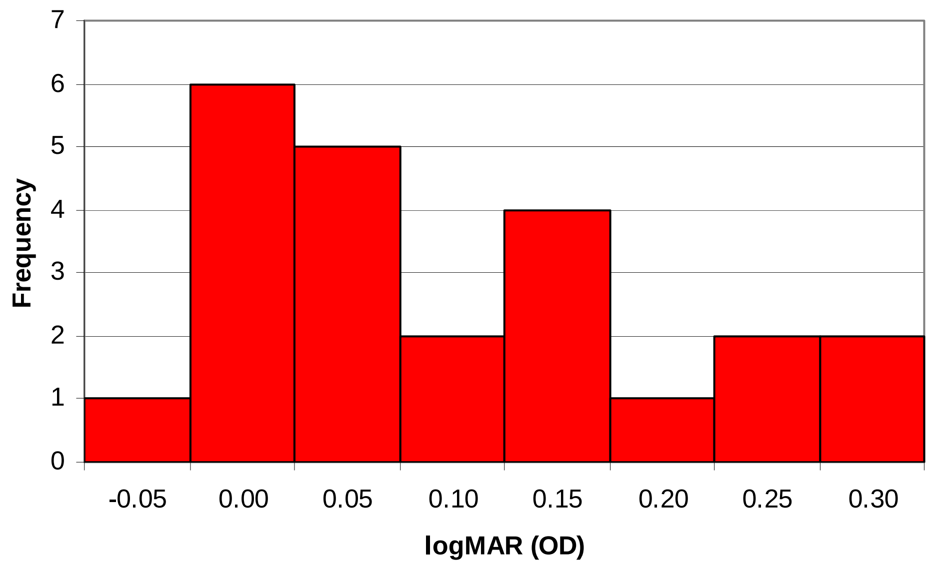
OD: Sphere_____ Cylinder_____ Axis_____
OS: Sphere_____ Cylinder_____ Axis_____

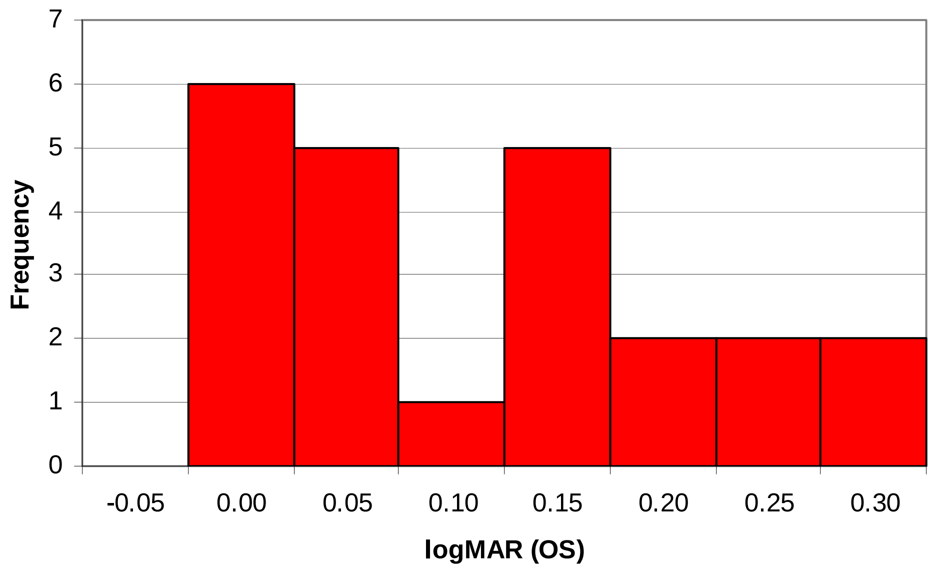




Bailey-Lovie high contrast visual acuity

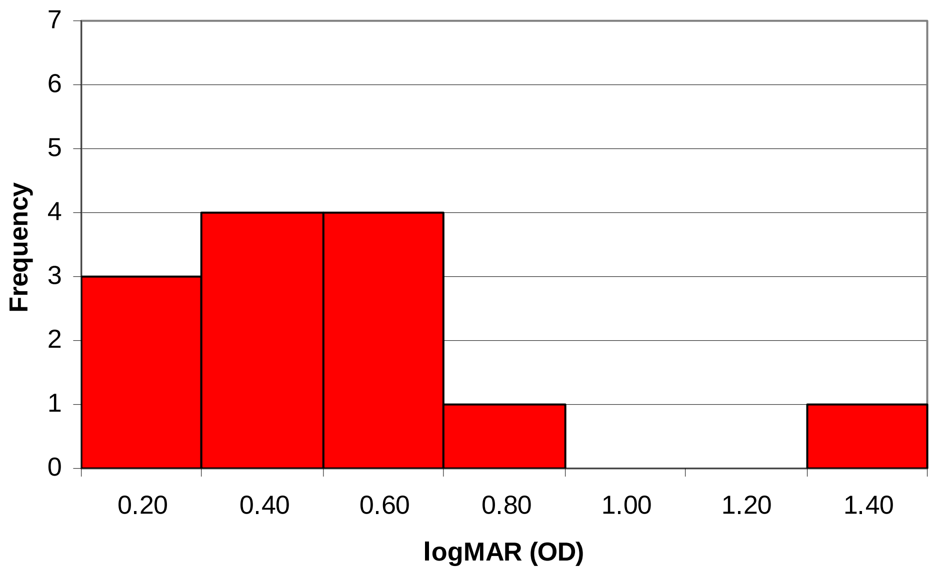
Total number missed for:
Right Eye:_____ Left Eye:_____

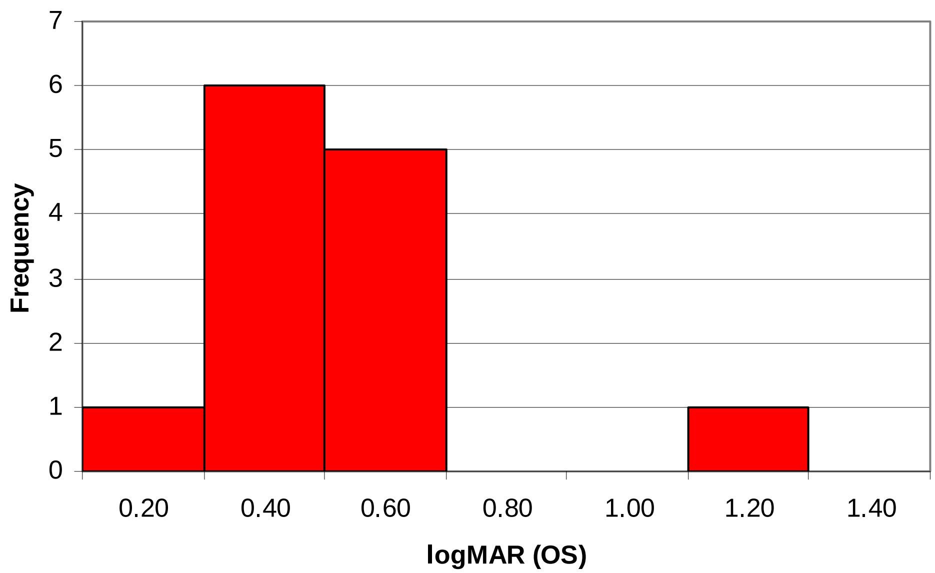




Bailey-Lovie low contrast visual acuity

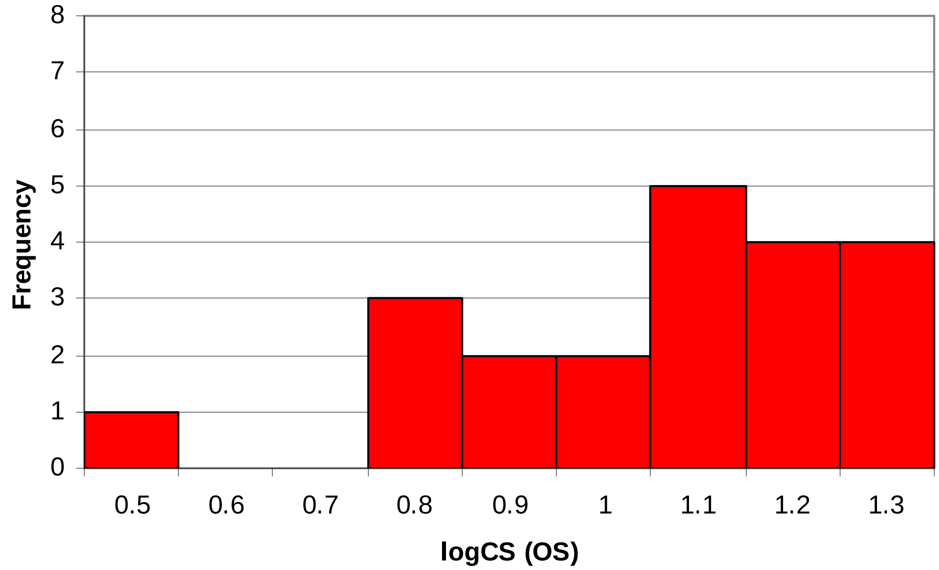
Total number missed for:
Right Eye:______   Left Eye:______

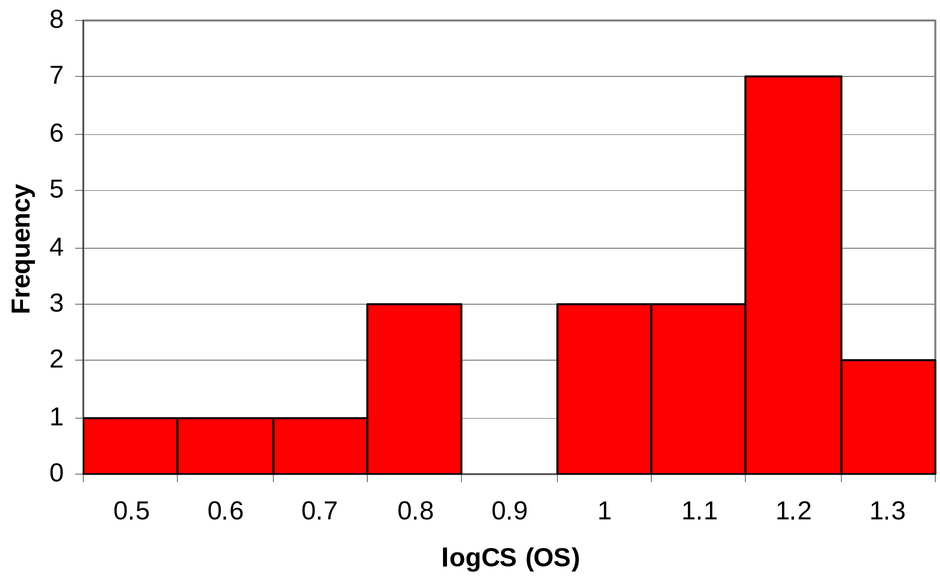




Small Letter Contrast Test (SLCT)

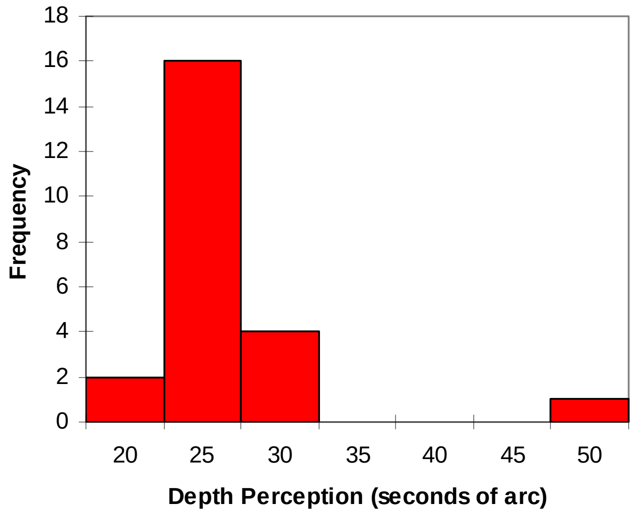
Total number missed for:
Right Eye:_____ Left Eye:_____





Depth perception

Minimum angle of stereopsis:



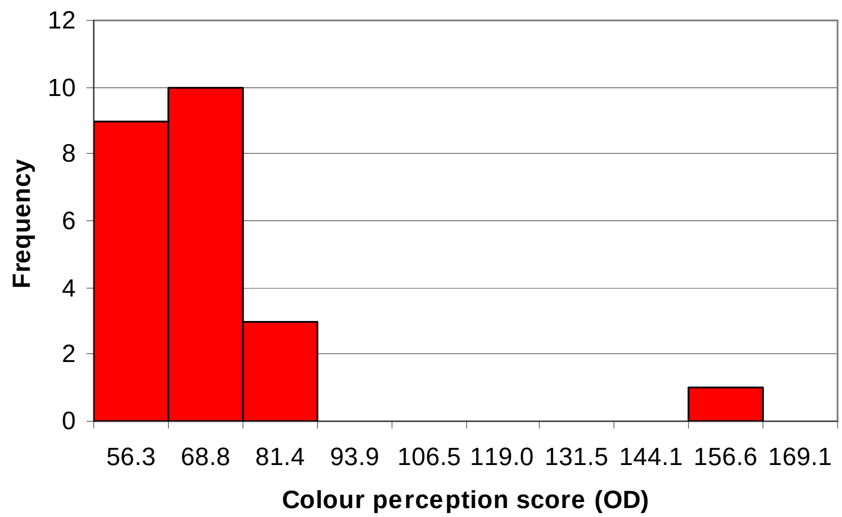
Color perception

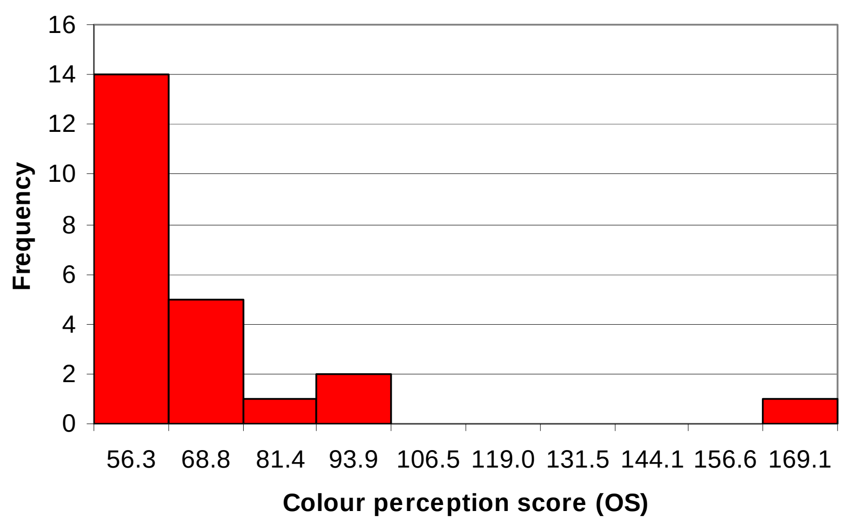
Right eye:
___ No reversal

__ __ __ __ __ __ __ __ __ __ __ __ __ __ __
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15

Left eye:
___ No reversal

__ __ __ __ __ __ __ __ __ __ __ __ __ __ __
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15

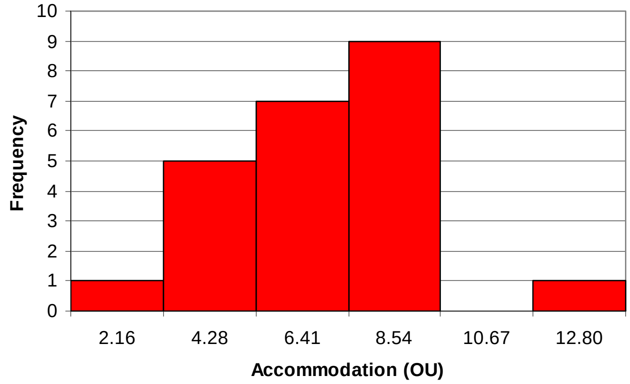


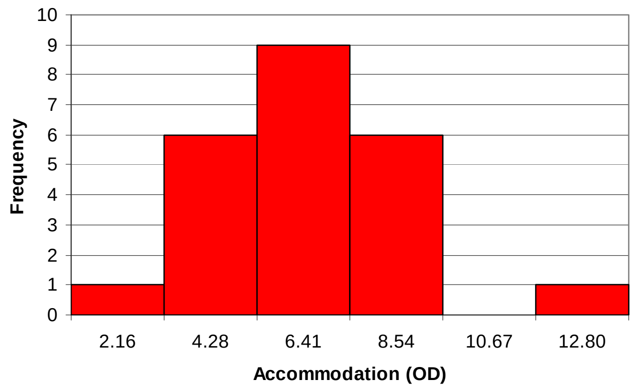


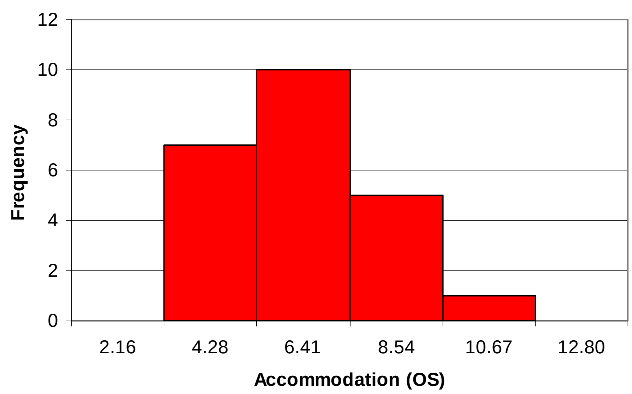
Accommodation

Without spectacles:

Both eyes: _____cm
Right eye: _____cm
Left eye: _____cm







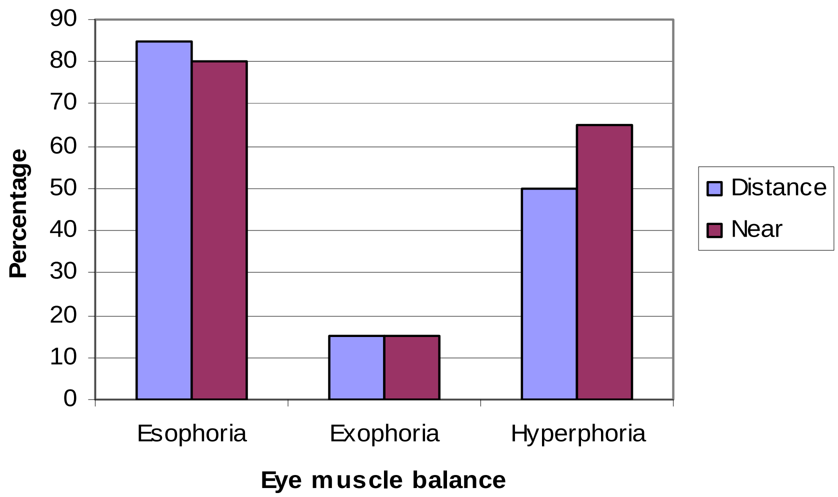
Eye muscle balance

Distance

Orthophoria: _____Yes   _____No
Heterophoria: _____ Exophoria _____
Hyperphoria: Right: ____ Left eye ____

Near

Orthophoria: _____Yes   _____No
Heterophoria: _____ Exophoria _____
Hyperphoria: Right: ____ Left eye ____



Eye preference

Right eye: ______ Left eye: ______

	Year 1	Year 2	Year 3	Year 4
Control	R (15, 65.2%) L (8, 34.8%)	R (12, 52.2%) L (6, 26.1%) N/R (5, 21.7%)	R (15, 65.2%) L (7, 30.4%) N/R (1, 4.3%)	R (7, 30.4%) L (3, 13.0%) N/R (13, 56.5%)

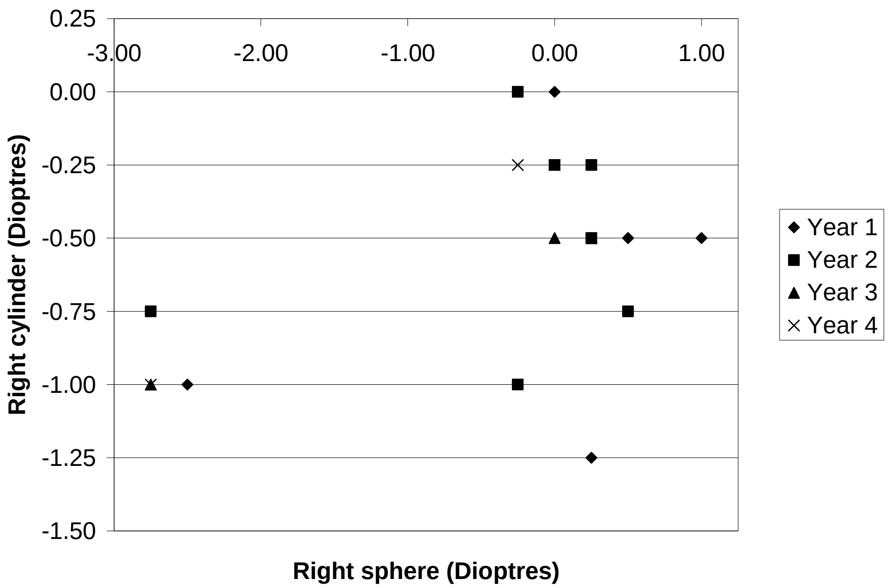
Appendix B.

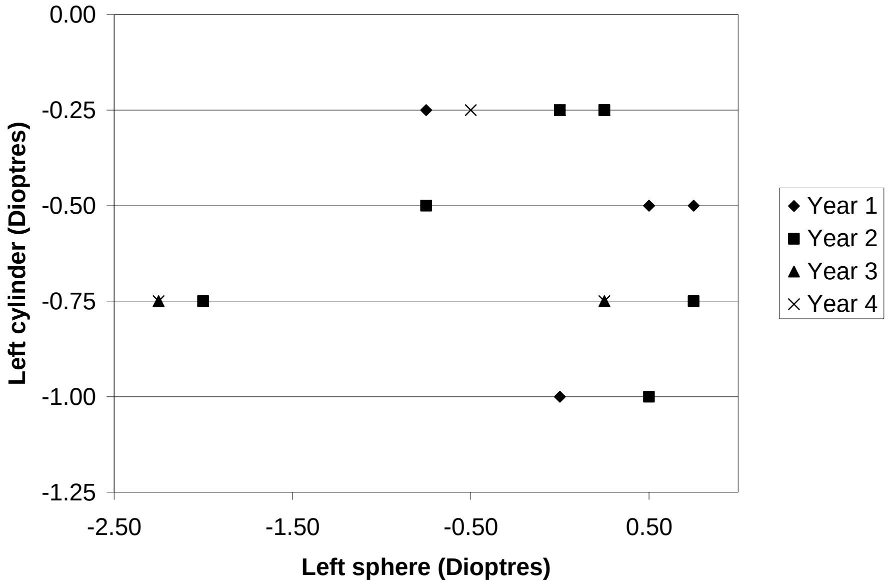
Apache AH Mk 1 (Exposed) pilot eye examination.

(includes last-year data only)

Manual refraction

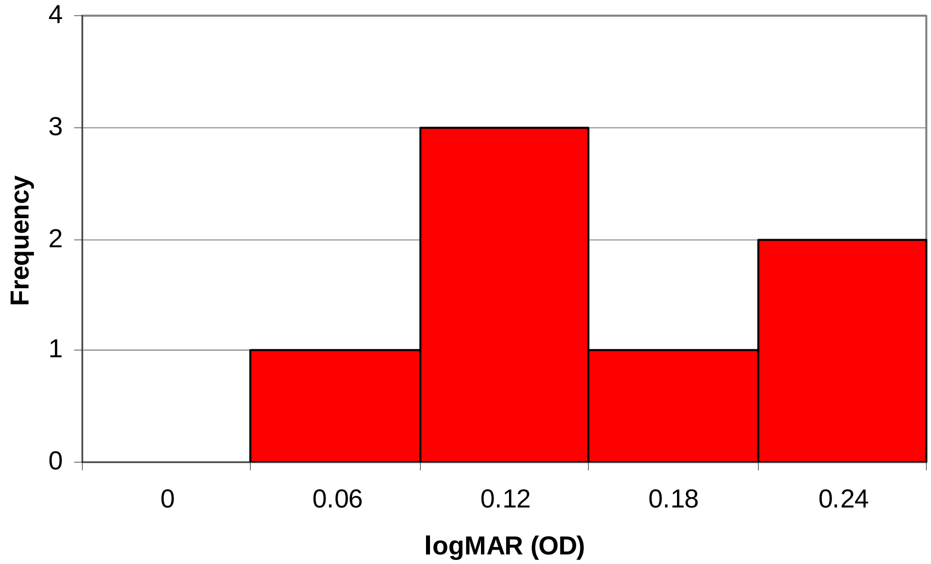
OD: Sphere_____ Cylinder_____ Axis_____
OS: Sphere_____ Cylinder_____ Axis_____

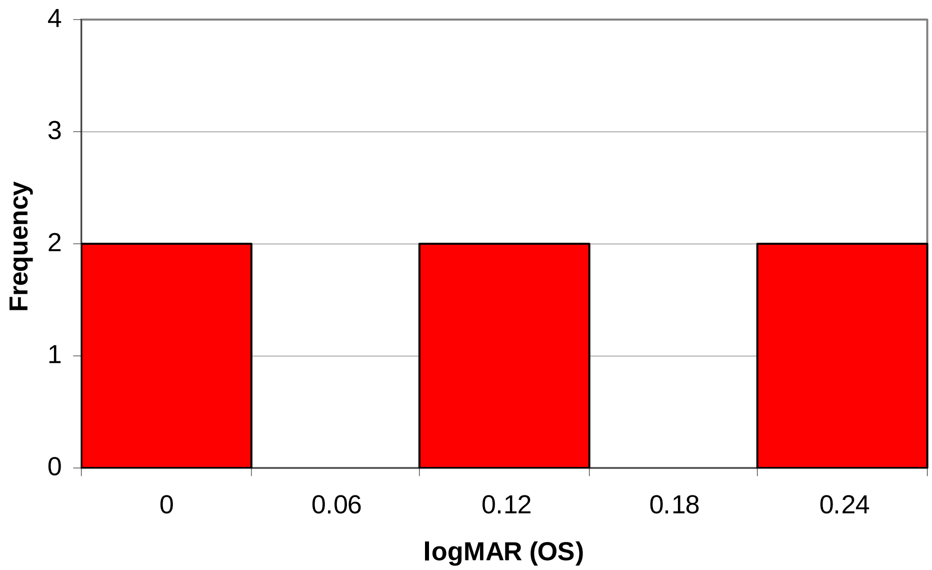




Bailey-Lovie high contrast visual acuity

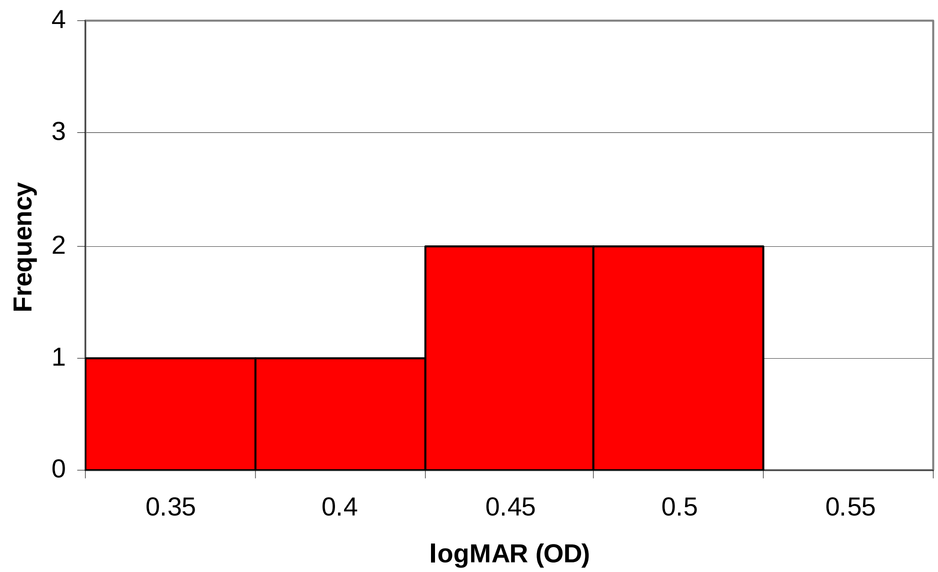
Total number missed for:
Right Eye:_____ Left Eye:_____

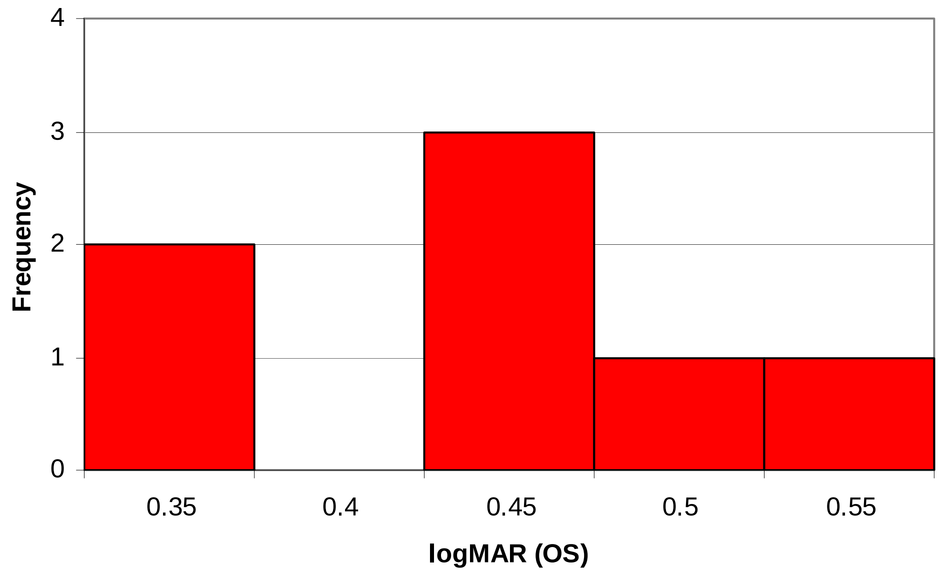




Bailey-Lovie low contrast visual acuity

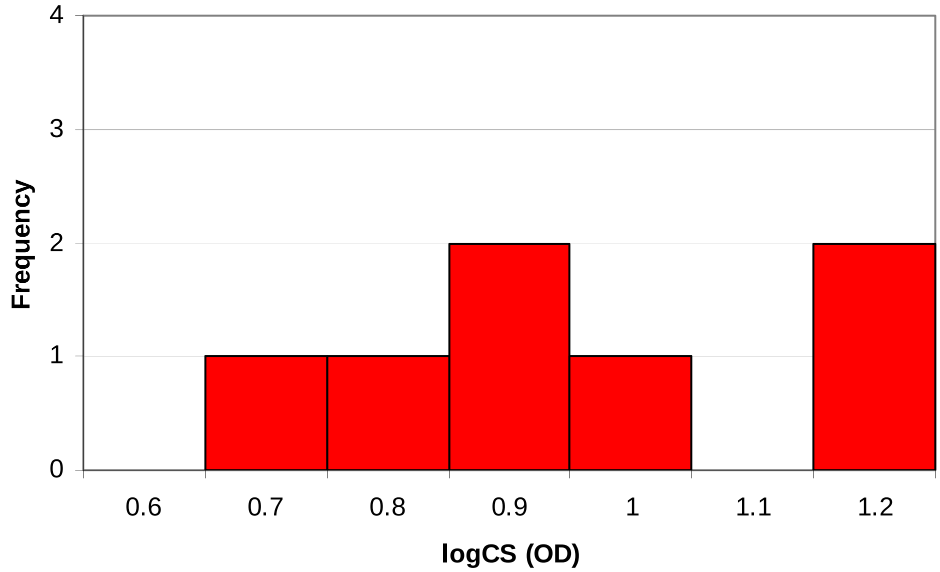
Total number missed for:
Right Eye:_____ Left Eye:_____

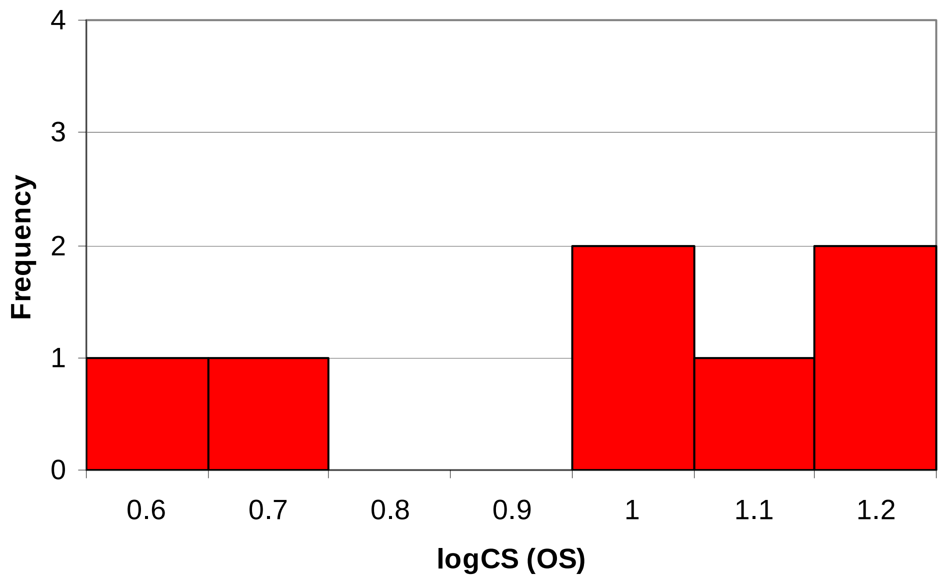




Small Letter Contrast Test (SLCT)

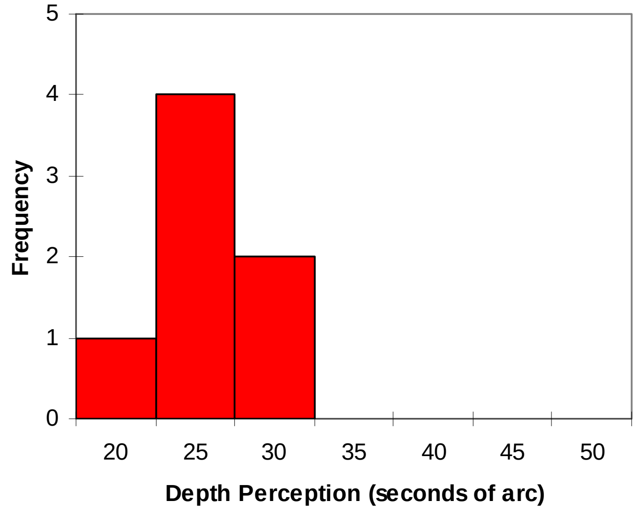
Total number missed for:
Right Eye:_____ Left Eye:_____





Depth perception

Minimum angle of stereopsis:



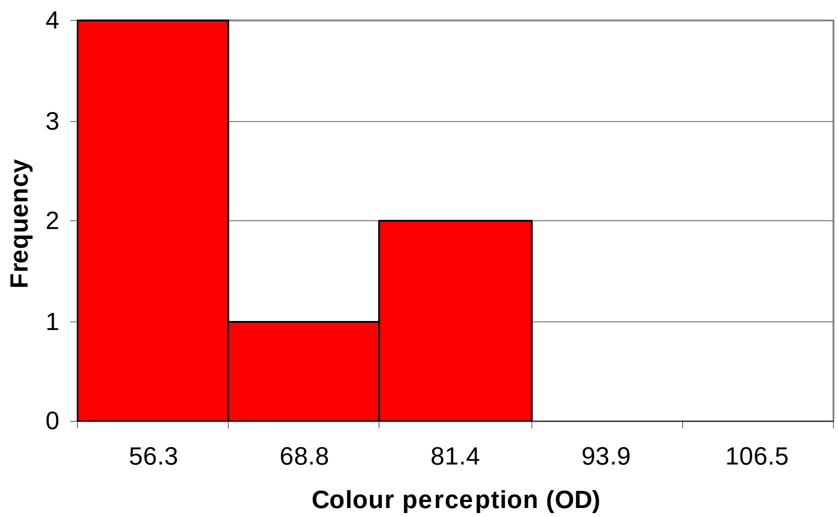
Color perception

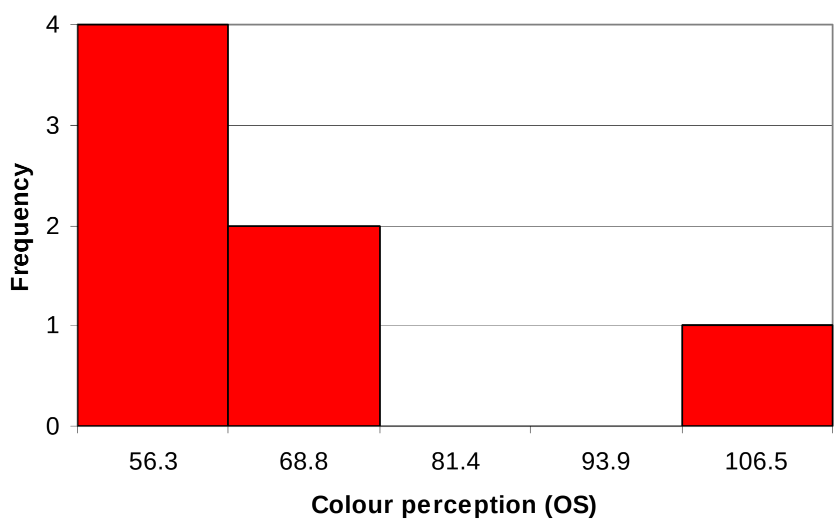
Right eye:
___ No reversal

__ __ __ __ __ __ __ __ __ __ __ __ __ __ __
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15

Left eye:
___ No reversal

__ __ __ __ __ __ __ __ __ __ __ __ __ __ __
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15

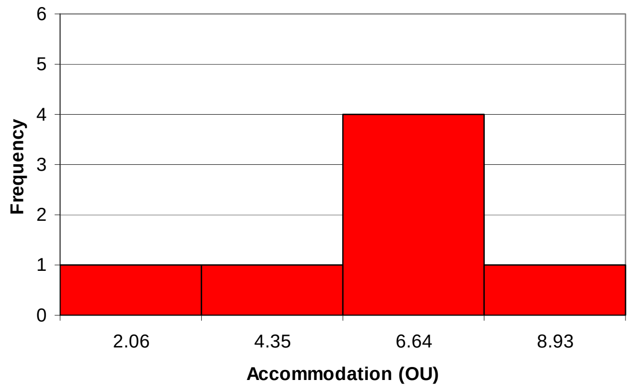


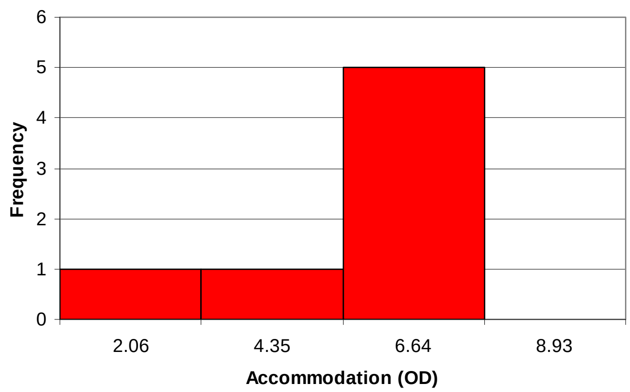


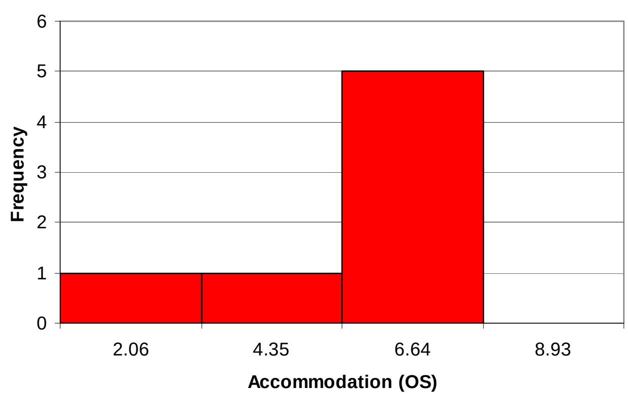
Accommodation

Without spectacles:

Both eyes: _____cm
Right eye: _____cm
Left eye: _____cm







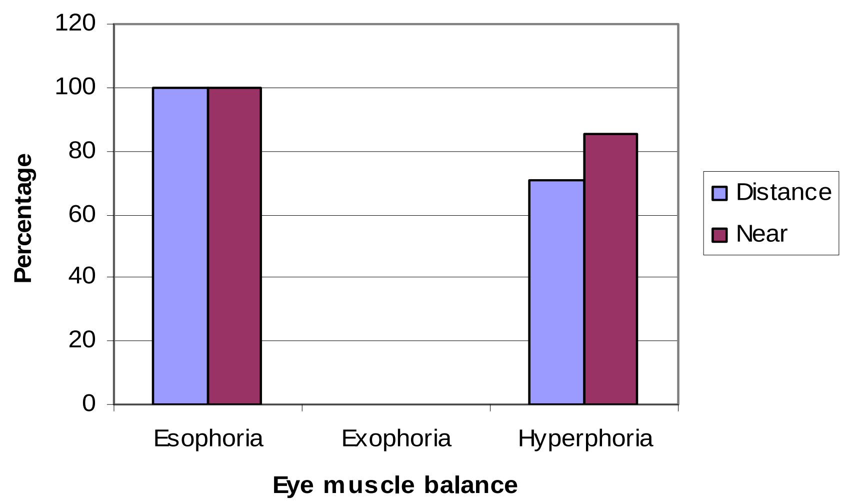
Eye muscle balance

<u>Distance</u>

Orthophoria: _____Yes   _____No
Heterophoria: _____ Exophoria _____
Hyperphoria: Right: ____ Left eye ____

<u>Near</u>

Orthophoria: _____Yes   _____No
Heterophoria: _____ Exophoria _____
Hyperphoria: Right: ____ Left eye ____



Eye preference

Right eye: ______ Left eye: ______

	Year 1	Year 2	Year 3	Year 4
Exposed	R (6, 85.7%) L (1, 14.3%)	R (6, 85.7%) L (0, 0%) N/R (1, 14.3%)	R (6, 85.7%) L (1, 14.3%)	R (2, 28.6%) L (3, 42.9%) N/R (2, 28.6%)

Appendix C.

List of acronyms.

AAC	Army Air Corps
ANVIS	Aviator’s Night Vision Imaging System
CA	Consultant Advisor
CFS	Corrective Flying Spectacles
CHS	Centre for Human Sciences
CRT	cathode ray tube
CS	contrast sensitivity
DAAvn	Director of Army Aviation
DERA	Defence Evaluation and Research Agency
EHI	Edinburgh Handedness Inventory
FLIR	forward-looking infrared
FOV	field-of-view
HDU	helmet display unit
HMD	helmet-mounted display
IHADSS	Integrated Helmet and Display Sighting System
MAR	minimum angle resolved
NVG	night vision goggles
PNVS	Pilot’s Night Vision System
QHI	Qualified Helicopter Instructor
SAM	Specialist in Aviation Medicine
SCL	soft contact lens
SD	spatial disorientation
SLCT	small letter contrast test
TADS	Target Acquisition and Designation System
USAARL	United States Army Aeromedical Research Laboratory
USXO	United States Army exchange officer

Department of the Army
U.S. Army Aeromedical Research Laboratory
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U.S. Army Medical Research and Materiel Command